THE PHYSIOLOGICAL EFFECTS OF MASSAGE POST EXERCISE IN HUMANS

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy by

Gareth Elfed Jones

December 2008

University of Chester

DECLARATION

This work of this thesis is original and has not been submitted previously in support of any qualification or course.

Signed ______ __________

Date 15th December 2008

ACKNOWLEDGEMENTS

Thank you to my supervisors, Professor David Cotterrell and Dr. Ian McDowall. Their commitment, enthusiasm and expert advice during this study have ensured that I worked to my full potential.

To my lovely, patient, and much neglected wife Sally Jones née Kibble, who has given me so much confidence and pragmatic advice over the last eight years. Thanks for convincing me to carry on, even when I was close to giving up (several times!). I love you very much.

Thanks very much to Clare Page for all her help in proof reading this thesis, particularly during the later stages, when she did a sterling job at such short notice.

Thank you to Molly, who has helped by listening intently to my inane drivel whilst out walking. I know you didn't actually say anything, but a wag of the tail is worth a thousand words.

I acknowledge and thank all the subjects who volunteered for this study. I would particularly like to thank six of the subjects, namely Ian Brooks, John Darby, Amy Grass, Jon Heath, Helen Marriott and Geraldine O'Kane for acting as photographic models. I also extend my sincere gratitude to the following people who assisted with the data collection, namely Andrew Appleyard, Stephen Clarke, Jane Cullingford, Stephen Froom, Jennifer Gammon, Jon Heath, Josie Moore, James Newman and Heather Elizabeth Roberts.

Sorry, to those unfortunate individuals who have shared an office with me over the last few years. Thanks for all your help and advice.

Finally, thank you to the staff of the Department of Biological Sciences and Department of Sport and Exercise Sciences who have helped by giving me advice, cups of coffee, scones, chocolate, and above all friendship.

ABSTRACT

Massage is a form of therapy which has been widely used for millennia, yet it remains an art which has limited scientific foundation. The aim of this study was to compare the physiological and psychological effects of traditional manual massage and newer mechanical vibratory massage techniques when administered at rest, or during recovery from exercise. In order to fully examine the effects of massage on recovery from exercise, three different types of exercise conditions were studied, namely aerobic, anaerobic and eccentric.

Manual and vibratory leg massage was administered at rest, and the results suggested that massage was effective at decreasing sympathetic and increasing parasympathetic activity, thus reducing heart rate, rate pressure product, and respiratory rate. Limb blood flow or metabolic rate were not altered; however, there was an increase in limb skin temperature indicating that massage may increase skin blood flow through the repeated mechanical friction. Massage also enhanced perceived psychological relaxation.

Leg massage, when administered following a bout of aerobic exercise, had a relaxation effect decreasing rate pressure product, and increasing cardiac parasympathetic activity, thus reducing the work of the heart. However, administering massage did not increase blood flow within the treated limb compared to resting alone. Massage enhanced the perceived feeling of relaxation during recovery, and for a period of time afterwards.

Leg massage was also administered following a bout of maximum intensity anaerobic exercise, and the results suggested that both massage modalities were effective at enhancing the clearance of lactate during short term recovery, compared to resting alone. In addition, the massage enhanced the feeling of relaxation and wellbeing during recovery, scoring higher than rest alone. This positive psychological effect is linked to, but cannot be attributed entirely to, enhanced lactate clearance. Massage did not reduce post exercise peripheral vasodilatation and subsequent diastolic hypotension.

Eccentric exercise was studied following a bout of biceps curls to exhaustion. The results indicated that vibratory arm massage was more effective than manual massage at reducing muscle pain induced by eccentric exercise. This effect did not appear to be mediated through less acute muscle damage, by decreased oedema, or by enhanced muscle strength recovery. The response may be due to a greater mechanical stimulation of the mechano and proprioceptors by vibratory massage, thus indicating a predominantly neural response.

The results presented in this study add to the body of empirical research evidence elucidating the physiological and psychological effects of mechanical vibratory massage. The data from the five investigations suggest that mechanical vibratory massage, in most respects, is equally as effective as manual massage when administered at rest, or during recovery from aerobic, anaerobic or eccentric exercise. This positive effect corroborates the unsubstantiated claims made by the manufacturer of the vibratory massage machine (G5®) used in this study, that the machine is as effective as manual massage.

PUBLISHED ABSTRACTS

Jones, G.E. & Cotterrell, D. (1999). Effect of leg massage on blood lactate removal following a single bout of maximum intensity cycling exercise in humans. *Journal of Physiology*, 518, 183.

Jones, G.E., Cotterrell, D., Froom, S., Gammon, J.A. & Brucelow, S.S. (2004). The effect of manual and vibratory leg massage following a bout of maximal intensity exercise. *Acta Physiolgica Scandinavia*, 181, A159.

Cotterrell, D., Jones, G.E., Bruce-Low, S.S., Froom, S. & Gammon, J.A. (2004). Lactate clearance after combining exercise and massage following a bout of maximum intensity cycling exercise. *Journal of Physiology*, 565, PC28.

Jones, G.E., Moore, J., Cotterrell, D. & Bruce-Low, S.S. (2004). Comparison of manual and mechanical vibratory massage following eccentric arm exercise. *Journal of Physiology*, 565, PC16.

Jones G.E., Cotterrell, D. & McDowall, I. (2007). Effect of leg massage on heart rate variability (HRV) following a bout of submaximal aerobic exercise. *Acta Physiologica Scandinavia*, 191, Supp 658, 64.

POSTER PRESENTATIONS

1999

The Physiological Society (London)
Effect of leg massage on blood lactate removal following a single bout of maximum intensity cycling exercise in humans. Jones, G.E. & Cotterrell, D.

2003

Scandinavian Congress of Physiology and Pharmacology (Odense)
The effect of manual and vibratory leg massage following a bout of maximal intensity exercise. Jones GE, Cotterrell D, Froom S, Gammon JA & Brucelow SS

The Physiological Society (London)
Lactate clearance after combining exercise and massage following a bout of maximum intensity cycling exercise. David Cotterrell, Gareth E. Jones, Stewart S. Bruce-Low, Stephen Froom and Jennifer A. Gammon

Comparison of manual and mechanical vibratory massage following eccentric arm exercise. Gareth E. Jones, Josie Moore, David Cotterrell and Stewart S. Bruce-Low

2005

XXXV International Union of Physiological Sciences (San Diego)

Vibratory massage reduces muscle pain following eccentric arm exercise. G.E. Jones, J. Moore, D. Cotterrell & S.S. Bruce-Low

Lactate clearance and perception of feeling during recovery from high intensity leg exercise. D. Cotterrell, G.E. Jones, S.S. Bruce-Low, S. Froom and J.A. Gammon

2007

Joint meeting of the Slovak Physiological Society, The Physiological Society and The Federation of European Physiological Societies (Bratislava)

Effect of leg massage on heart rate variability (HRV) following a bout of submaximal aerobic exercise. Jones G.E., Cotterrell, D. & McDowall, I.

2008

The Physiological Society (Cambridge)

Effect of leg massage on heart rate variability (HRV) in healthy subjects. Jones G.E., Cotterrell, D. & McDowall, I.

PUBLICATIONS FROM OTHER RESEARCH ACTIVITIES

Ryder, J.J., Grantham, N., Kellett, D. McNaughton, L., Lovell, R, & Jones, G.E. (2004). Marathon Des Sables: A Scientific Case Study. *Research in Sports Medicine: An International Journal*, 12(1), 33-44.

Costa, R.J.S., Jones, G.E., Coleman, R., Lamb, K.L. & Williams, J.H.H (2005). The effects of a high carbohydrate diet on cortisol and salivary Immunoglobulin a (s-IgA) during a period of increase exercise workload amongst Olympic and Ironman triathletes. *International Journal of Sports Medicine*, 26(10), 880-885.

Robins, A., Davies, D. & Jones, G.E. (2005). The effect of nutritional manipulation on ultra-endurance performance: A case study. *Research in Sports Medicine: An International Journal*, 13(3), 199-215.

Bruce-Low, S., Cotterrell, D. & Jones, G.E. (2006). Heart Rate Variability during high ambient heat exposure. *Aviation, Space and Environmental Medicine*, 77(9), 915-920.

Bruce-Low, S.S., Cotterrell, D. & Jones, G.E. (2007). Effect of wearing personal protective clothing and self-contained breathing apparatus on heart rate, temperature and oxygen consumption during stepping exercise and live fire training exercises. *Ergonomics*, 50(1), 80-98.

TABLE OF CONTENTS

	Page number(s)
Title page	i
Declaration	ii
Acknowledgements	iii
Abstract	iv-v
Published abstracts, poster presentations and publications from other research activities	vi-vii
Thesis contents	viii-xiii
List of Figures	xiv-xxi
List of Tables	xxii-xxv
Abbreviations	xxvi- xxvii

CHAPTER 1: 1-39

Introduction and review of literature

1.1	Overview...	2
1.2	A brief history of manual massage....................................	2-4
1.3	Classification of the massage type used during the study, and the proposed physiological and psychological effects of massage on the human body..	4-6
1.4	The effect of massage on cardiac autonomic activity, with specific reference to alterations in heart rate and heart rate variability.......	6-13
1.5	Effect of massage on the cardiovascular system (blood pressure and rate pressure product)...	13-14
1.6	The effect of massage on metabolic rate (oxygen consumption and carbon dioxide production)...	14-17
1.7	The effect of massage on respiration (pulmonary ventilation, respiratory rate and tidal volume)..	17-18
1.8	The effect of manual and vibratory massage on limb blood flow...	18-23
1.9	The effect of massage on blood lactate concentration following exercise...	23-27
1.10	Is massage as a method of decreasing the indices of acute muscle damage following eccentric exercise to exhaustion (creatine kinase concentration, and muscle pain)?.......................................	27-31
1.11	Massage as a method to promote acute muscle damage healing (reduction in limb swelling and restoration in muscle strength......	31-34
1.12	The psychological effects of massage..................................	34
1.13	Comparison between the massage methods used in this study.......	34-37
1.14	Study aims and research questions	37-38
1.15	Hypothesis	39

CHAPTER 2: **40-53**

Massage techniques & general materials and methods

2.1 Massage techniques used in this study.......... 41
2.2 Manual massage techniques.......... 41-44
2.3 Vibratory massage techniques.......... 44-46
2.4 Duration of massage administration in the present study.......... 46-47
2.5 General materials and methods.......... 47-53
2.6 Ethical approval.......... 53

CHAPTER 3: **54-90**

The effect of whole leg massage administered at rest (Investigation 1)

&

The effect of single leg calf massage administered at rest (Investigation 2)

Introduction.......... 55
Aims.......... 56
Specific materials and methods.......... 57-62
Results: Investigation 1.......... 63-68
Results: Investigation 2.......... 69-76
Discussion.......... 77-89
Conclusions.......... 90

CHAPTER 4: **91-110**

The effect of a single whole leg massage following a bout of aerobic cycling exercise (Investigation 3)

Introduction.......... 92
Aims.......... 93
Specific materials and methods.......... 94-96
Results: Investigation 3.......... 97-106

Discussion.. 107-109

Conclusions.. 110

CHAPTER 5: **111-155**

The effect of continuous and combined leg massage on recovery from anaerobic exercise (Investigation 4)

Introduction.. 112-113

Aims.. 114-115

Specific materials and methods.. 116-120

Results: Investigation 4.. 121-141

Discussion.. 142-154

Conclusions.. 155

CHAPTER 6: **156-188**

The effect of an arm massage following a bout of eccentric exercise (Investigation 5)

Introduction.. 157-160

Aims.. 161

Specific materials and methods.. 162-167

Results: Investigation 5.. 168-176

Discussion.. 177-187

Conclusions.. 188

CHAPTER 7: **189-237**

Discussion

7.1 Overview.. 190

7.2 The effect of manual and vibratory on cardiac autonomic activity, heart rate, blood pressure and rate pressure product........................ 190-192

7.3 The effect of manual and vibratory massage on respiration.. 193

7.4	The effect of manual and vibratory massage on leg skin and aural temperature..........	193
7.5	The effect of manual and vibratory massage on limb blood flow (measured using a plethysmograph)..........	194
7.6	The effect of manual and vibratory massage on blood lactate concentration following exercise..........	194-196
7.7	The effects of manual and vibratory massage on psychological wellbeing..........	196-198
7.8	Is the physiological and psychological response of manual and vibratory massage administered at rest similar to the response when massage is administered during recovery from exercise?..........	198-199
7.9	Is there any difference in the physiological and psychological response between manual and vibratory massage?..........	199-201
7.10	Overall study conclusions..........	201
7.11	Directions of future research..........	201-203

REFERENCES **204-222**

APPENDICES

Appendix 1: **224-231**

Test-retest reliability of the Polar 810*i*™ as a time and frequency domain measurement of heart rate variability.

Introduction..........	224
Aims..........	224
Materials and methods..........	225
Results..........	226-231
Conclusions..........	231-232

Appendix 2: **233-251**

The effect of a continuous manual leg massage on recovery from anaerobic exercise

Introduction.. 233

Aims.. 233

Materials and methods.. 234-236

Results.. 237-251

Conclusions.. 251

Appendix 3: **252-259**

The effect of controlled and spontaneous breathing on components of heart rate variability

Introduction.. 252-253

Aims.. 253

Materials and methods.. 254

Results.. 255-259

Conclusions.. 259

Appendix 4: **260-270**

Appendix 4.1 Pre-test Health Questionnaire 260

Appendix 4.2 Informed consent for 30mins massage at rest 263

Appendix 4.3 Informed consent for 10mins massage at rest 264

Appendix 4.4 Informed consent for aerobic exercise 265-266

Appendix 4.5 Informed consent for anaerobic exercise 267-268

Appendix 4.6 Informed consent for eccentric exercise 269

Appendix 4.7 Subject consent form 270

LIST OF FIGURES

		Page number
	INTRODUCTION	
Figure 1.1	The distribution of power within the HRV components. The areas on the graphs that are represented by the VLF, LF, and HF frequencies are depicted by the different lines (refer to the key). ***a)*** A representative 5min sample taken after 10mins of seated rest prior to sauna exposure using the fast fourier method of obtaining a power spectral density graph in thermoneutral conditions (room temperature maintained at 27±0.7°C; HR 75bpm). ***b)*** A 5min sample obtained during the final 5mins of a 15min sauna exposure using the fast fourier method of obtaining a power spectral density graph (74.3±5.9°C; HR 135bpm). Data from Bruce-Low, Cotterrell & Jones (2006).	11
Figure 1.2	Tibialis anterior blood circulation pre (A) and post massage (B) (Reproduced from Dubrovsky, 1982).	20
Figure 1.3	Femoral artery mean blood velocity at rest and during 5mins of effleurage, petrissage, tapotement forms of massage, and following brief voluntary quadriceps contraction. Arrow indicates onset of massage or exercise (Reproduced from Shoemaker, Tiidus & Mader, 1997).	22
Figure 1.4	Blood lactate concentration after high intensity exercise bouts (data from Robertson, Watt & Galloway, 2004).	27
Figure 1.5	Line of best fit (linear) for means of serum creatine kinase for massage (N=7) and control (N=7) subjects (Data from Smith *et al.*, 1994).	28
Figure 1.6	Time-course of post-eccentric exercise delayed onset muscle soreness (DOMS) for massage and control legs *Control *vs* Massage p<0.05 (Data from Tiddus & Shoemaker, 1995).	30
Figure 1.7	Changes in upper arm circumference 8cm above the elbow joint (CIRM) and 4cm below the elbow joint (CIRD) following 24 maximal eccentric biceps contractions (* p<0.05) (Data from Nosaka & Clarkson, 1996).	32
Figure 1.8	Changes in maximal voluntary isometric torque from baseline (Data from Zainuddin, Newton, Sacco & Nosaka, 2005).	34
	MASSAGE TECHNIQUES & GENERAL MATERIALS AND METHODS	
Figure 2.1	Areas of the hand used during a massage	42
Figure 2.2	Superficial effleurage of the left quadriceps	42
Figure 2.3	Deep effleurage of the right calf	42
Figure 2.4	Kneading of the right calf	43
Figure 2.5	Kneading of the right tibialis anterior	44
Figure 2.6	Wringing of the right hamstring	44
Figure 2.7	G5® 'Workout Masseur' vibratory massage machine	45
Figure 2.8	Directional force and axis of rotation of the G5® weighted head	45

Figure 2.9	U-shaped sponge adaptor (applicator 230). Used on larger areas such as quadriceps and hamstrings to simulate effleurage	46
Figure 2.10	Round sponge adaptor (applicator 210). Used on smaller areas such as calf and triceps to simulate effleurage	46
Figure 2.11	4 ball adaptor (applicator 216). Used on larger areas such as hamstrings to simulate petrissage	46
Figure 2.12	2 ball adaptor (applicator 223). Used on smaller areas such as biceps and anterior tibialis to simulate petrissage	46
Figure 2.13	PVL-50 Series 2 portable plethysmograph	51
Figure 2.14	Leg position adopted during the collection of the plethysmography data. Cuffs were placed around the leg at the maximum circumference of the calf and thigh.	51
Figure 2.15	Venous volume displacement curve obtained from a healthy adult leg using a SkiMed PVL-50 plethysmograph, with annotated events.	52
Figure 2.16	Calculation to estimate limb blood flow from a curve obtained from a healthy female adult leg using a SkiMed PVL-50 plethysmograph.	52

CHAPTER 3

Investigation 1

Figure 3.1	Position adopted by the subjects during Investigation 1	58
Figure 3.2	Individual subjects (thin grey lines) and mean (thick coloured line) heart rate response following 30mins of Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10).	63
Figure 3.3	Individual subjects (thin grey lines) and mean (thick coloured line) sympathovagal (LF:HF ratio) response following 30mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10).	64
Figure 3.4	Correlation (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.	66

Investigation 2

Figure 3.5	Individual subjects (thin grey lines) and mean (thick coloured line) heart rate response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).	69
Figure 3.6	Individual subjects (thin grey lines) and mean (thick coloured line) sympathovagal (LF:HF ratio) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).	71
Figure 3.7	Correlation (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.	73

CHAPTER 4 (Investigation 3)

Figure 4.1	Heart rate (bpm) response following a 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), 20mins Manual leg Massage (MM) and 20mins Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = MM *vs* R and ***b*** = VM vs R	97
Figure 4.2	Systolic and diastolic blood pressure (mmHg) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage	100

	(MM) and Vibratory leg Massage (VM) (n=6).	
Figure 4.3	Rate pressure product (HR x SBP) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), 20mins Manual leg Massage (MM) and 20mins Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, ***c*** = MM *vs* Baseline, and ***d*** = VM *vs* Baseline	101
Figure 4.4	Correlation coefficient (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.	101
Figure 4.5	Leg skin temperature (°C) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, ***c*** = MM *vs* VM, and ***d*** = 30mins post exercise *vs* baseline (all recovery modes)	102
Figure 4.6	Aural temperature (°C) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = all conditions *vs* baseline, ***b*** = MM *vs* baseline, ***c*** = VM *vs* baseline and ***d*** = R *vs* baseline.	103
Figure 4.7	Blood lactate (mmol · l^{-1}) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6).	105
Figure 4.8	Perception of feeling response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Data presented as Median ± Interquartile range. Significant differences ***a*** = MM *vs* R, ***b*** = VM vs R and ***d*** = 30mins post exercise *vs* Baseline (R)	106

CHAPTER 5 (Investigation 4)

Figure 5.1	A subject following the Wingate Anaerobic Test.	117
Figure 5.2	Position adopted during recumbent cycling.	119
Figure 5.3a	Blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE *vs* MM+MM, ***b*** = CE+CE *vs* VM+VM, ***c*** = CE+CE *vs* R+R, ***d*** = MM+MM *vs* R+R and ***e*** = VM+MM *vs* R+R (n = 10).	122
Figure 5.3b	Blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R)). Significant differences ***a*** = CE+CE *vs* CE+MM, ***b*** = CE+CE *vs* CE+VM and ***c*** = CE+CE *vs* CE+R (n = 10). ∇ Change in recovery method following 15mins cycling exercise.	124
Figure 5.4a	Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for continuous manual leg massage (MM+MM).	122
Figure 5.4b	Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for continuous vibratory leg massage (VM+VM).	123
Figure 5.5a	Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise	125

	for manual leg massage (MM+MM).	
Figure 5.5b	Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for vibratory leg massage (VM+VM).	123
Figure 5.6a	Heart Rate (bpm) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ($p<0.0001$) ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE vs VM+VM, ***c*** = CE+CE vs R+R ($n = 10$).	126
Figure 5.6b	Heart Rate (bpm) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ($p<0.001$) ***a*** = CE+CE vs CE+MM, ***b*** = CE+CE *vs* CE+VM, ***c*** = CE+CE *vs* CE+R (n = 10). ▼ Change in recovery method following 15mins cycling exercise.	126
Figure 5.7a	Systolic Blood Pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE vs VM+VM and ***c*** = CE+CE vs R+R ($n = 10$).	127
Figure 5.7b	Systolic Blood Pressure (mmHg) response following a bout of maximal intensity comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences at 20mins post ***a*** = CE+CE *vs* CE+MM, ***b*** = CE+CE *vs* CE+VM, ***c*** = CE+CE *vs* CE+R ($n = 10$). ▼ Change in recovery method following 15mins cycling exercise.	128
Figure 5.8a	Diastolic Blood Pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE vs VM+VM, ***c*** = CE+CE vs R+R ($n = 10$).	129
Figure 5.8b	Diastolic Blood Pressure (mmHg) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences at 20mins post ***a*** = CE+CE vs CE+MM, ***b*** = CE+CE *vs* CE+VM, ***c*** = CE+CE *vs* CE+R ($n = 10$). ▼ Change in recovery method following 15mins cycling exercise.	130
Figure 5.9a	Oxygen consumption (ml O_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE *vs* MM+MM, ***b*** = CE+CE *vs* VM+VM and ***c*** = CE+CE *vs* R+R ($n = 10$).	133
Figure 5.9b	Oxygen consumption (ml O_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+CE *vs* CE+MM, ***b*** = CE+CE *vs* CE+VM and ***c*** = CE+CE *vs* CE+R ($n = 10$). ▼ Change in recovery method following 15mins cycling exercise.	134
Figure 5.10a	Respiratory Exchange Ratio response following a bout of maximal intensity	135

	exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R) (n = 10).	
Figure 5.10b	Respiratory Exchange Ratio response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). ▼ Change in recovery method following 15mins cycling exercise (n = 10).	135
Figure 5.11a	Aural temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE *vs* VM+VM, ***c*** = CE+CE *vs* R+R (n = 10).	137
Figure 5.11b	Aural temperature (°C) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg Massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Repeated measures ANOVA significant differences (p<0.05). Significant differences ***a*** = CE+CE *vs* CE+R ▼ Change in recovery method following 15mins cycling exercise (n = 10).	138
Figure 5.12a	Perception of Feeling (PoF) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = MM+MM *vs* R+R, ***b*** = MM+MM vs CE+CE, ***c*** = MM+MM *vs* VM+VM, ***d*** = VM+VM *vs* R+R and ***e*** = CE+CE *vs* R+R (n = 10).	139
Figure 5.12b	Perception of Feeling (PoF) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+MM *vs* CE+R, ***b*** = CE+MM *vs* CE+CE, ***c*** = CE+VM *vs* CE+R (n = 10). ▼ Change in recovery method following 15mins cycling exercise.	140
Figure 5.13	The activity periods of six muscle groups during one revolution of the pedals during a Wingate Anaerobic Test (Reproduced from Faria & Cavanagh, 1978).	144
Figure 5.14a	Changes in oxygen consumption following various modes of recovery (n=10) (Data from Gupta, Goswami, Sadhukhan & Mather (1996).	152
Figure 5.14b	Changes in carbon dioxide production following various modes of recovery (n=10) (Data from Gupta, Goswami, Sadhukhan & Mather (1996).	152

CHAPTER 6 (Investigation 5)

Figure 6.1	Potential treatments for delayed onset muscle soreness (From Connolly, Sayers & McHugh, 2003).	158
Figure 6.2a	Standardised standing position (preacher curl) adopted during the bout of eccentric biceps exercise. The eccentric contraction extended the elbow from 50° to 170°, and lasted 10secs.	164
Figure 6.2b	Assistance was then given with the 2sec concentric phase.	164
Figure 6.3	Effleurage of the forearm extensors with the arm supported on a therapy couch	164

Figure 6.4	Petrissage of the triceps	164
Figure 6.5	Limb circumference measured 3cm below (marked in red) the crease of the elbow (green line), by an experienced technician using a non-stretch flexible tape and marked with a permanent pen	166
Figure 6.6	Rating of perceived exertion for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30).	168
Figure 6.7	Creatine kinase concentration (U/L) for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences ***a*** = 120hrs *vs* baseline.	170
Figure 6.8	Individual subjects (thin grey lines) and mean (thick coloured line) creatine kinase concentration (U/L) for rest (R), for manual massage (MM) and vibratory massage (VM) prior to and for 120hrs following a bout of eccentric exercise (n = 30).	170
Figure 6.9	Limb circumference measurement for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences ***a*** = 120hrs *vs* baseline.	171
Figure 6.10	Muscle strength for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). 100% muscle strength = 1 repetition maximum. Significant differences ***a*** = 120hrs *vs* baseline.	172
Figure 6.11	Perception of pain for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences (p<0.01) ***a*** = VM *vs* R and ***b*** = VM *vs* MM.	173
Figure 6.12	Individual subjects (thin grey lines) and mean (thick coloured line) perception of pain for vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 10).	174
Figure 6.13	Perception of feeling for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences (p<0.01) ***a*** = MM *vs* R and ***b*** = VM *vs* R.	175
Figure 6.14	Correlation between perception of pain (a measurement of muscle pain) and perception of feeling (a marker of mood) for up to 24hrs post eccentric exercise bout.	176
Figure 6.15	Changes in plasma creatine kinase (CK) activity before (pre) and 1 to 14 days post exercise for the massage and control arms. * Indicates a significant difference between arms; #, a significant difference from baseline. (Data from Zainuddin, Newton, Sacco & Nosaka, 2005).	179
Figure 6.16a	Pain action potentials transmitted via the A-delta and C fibres synapse with the first interneuron (adapted form Kandell, Shwartz & Jessell, 2000).	182
Figure 6.16b	Firing of the A-beta fibers actives the inhibitory interneuron, reducing the possibility that the projection neuron will fire, even in the presence of a firing A-delta and C fibers (adapted from Kandell, Shwartz & Jessell, 2000).	182

APPENDIX 1

Figure A1.1	Correlation analysis for Test 1 *vs* Test 2 for heart rate (r^2=0.9924)	228
Figure A1.2	Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for heart rate	228
Figure A1.3	Correlation analysis for Test 1 *vs* Test 2 for LFnorm (r^2=0.9947)	229

Figure A1.4	Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for Lfnorm	229
Figure A1.5	Correlation analysis for Test 1 *vs* Test 2 for Hfnorm (r^2=0.9948)	230
Figure A1.6	Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for Hfnorm	230
Figure A1.7	Correlation analysis for Test 1 *vs* Test 2 for LF:HF ratio (r^2=0.9923)	231
Figure A1.8	Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for LF:HF ratio	231

APPENDIX 2

Figure A2.1	Blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM, ***b*** = CE vs R and *c* = MM *vs* R (*n* = 10).	238
Figure A2.2	Estimated total clearance time of blood lactate (mmol · l^{-1}) to baseline following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM, ***b*** = CE *vs* R and ***c*** = MM *vs* R (*n* = 10).	238
Figure A2.3	Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for manual leg massage (MM).	239
Figure A2.4	Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for continued cycling exercise (CE).	239
Figure A2.5	Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for rest (R).	239
Figure A2.6	Heart rate (bpm) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM and ***b*** = CE *vs* R (*n* = 10).	240
Figure A2.7	Systolic blood pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R) (*n* = 10).	241
Figure A2.8	Diastolic blood pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences for diastolic blood pressure ***a*** = CE *vs* MM and ***b*** = CE *vs* R (*n* = 10).	242
Figure A2.9	Rate pressure product (units) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM, ***b*** = CE vs R and ***c*** = MM *vs* R (*n* = 10).	243
Figure A2.10	Correlation (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.	244
Figure A2.11	Oxygen consumption (ml O_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** =	246

	CE *vs* MM and ***b*** = CE *vs* R (n = 10).	
Figure A2.12	Carbon dioxide production (ml CO_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences (p<0.05) ***a*** = CE *vs* MM and ***b*** = CE *vs* R (n = 10).	247
Figure A2.13	Respiratory Exchange Ratio response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R) (n = 10). Significant differences ***a*** = CE *vs* MM and ***b*** = CE *vs* R (n = 10).	248
Figure A2.14	Aural temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM and ***c*** = MM *vs* R (n = 10).	249
Figure A2.15	Perception of Feeling response following a bout of maximal intensity exercise for 30mins recumbent Cycling Exercise (CE), 30mins Manual leg Massage (MM) and 30mins Rest (R). Significant differences ***a*** = MM *vs* CE, ***b*** = CE *vs* R and ***c*** = MM *vs* R (n = 10).	250

APPENDIX 3

Figure A3.1	Power spectral density (PSD) graph showing the effect of controlled breathing (CB). Graph depicts the power distribution of the HRV components. The areas on the graph that are represented by the VLF, LF and HF frequencies are depicted by the different lines (refer to the key). Results were obtained during seated rest when breathing frequency was controlled (CB) at 0.20±0.0Hz (n = 1) at room temperature (21 - 24°C) for a period of 5mins	256
Figure A3.2	Power spectral density (PSD) graph showing the effect of spontaneous breathing (SB). Graph depicts the power distribution of the HRV components. The areas on the graph that are represented by the VLF, LF and HF frequencies are depicted by the different lines (refer to the key). Results were obtained during seated rest when breathing frequency was spontaneous (SB) at 0.20±0.9Hz (n = 1) at room temperature (21 - 24°C) for a period of 5mins	256
Figure A3.3	The effect of controlled breathing (CB) using a heart rate (HR) R-R interval tachogram (Polar software (Finland, Oy)). Data was obtained in at an ambient room temperature which was maintained between 21 - 24°C, with the subject seated rest for a period of 5mins. Breathing frequency was controlled at 0.20±0.0Hz.	258
Figure A3.4	The effect of spontaneous breathing (SB) using a heart rate (HR) R-R interval tachogram (Polar software (Finland, Oy)). Data was obtained in at an ambient room temperature which was maintained between 21 - 24°C, with the subject seated at rest for a period of 5mins.	258

LIST OF TABLES

		Page number
	INTRODUCTION	
Table 1.1	Physiological and psychological effects of manual and vibratory massage (Stamford, 1985; Cafarelli, Sim, Carolan & Liebsman, 1990; Morsaka, 2005; Weerapong, Hume & Kolt, 2005; DeDomenico, 2007; and G5® Europe website, 2008).	6
Table 1.2	Effect pre- and post- 20min neck, shoulder and back massage on heart rate, blood pressure and sympathovagal balance (Delaney, Leong, Watkins & Brodie, 2002) (Mean±SE).	12
Table 1.3	The effects of massage on blood flow at rest and/or at rest following a bout of exercise (↔ No change; ↑ Increase) (R administered at rest; PE = at rest post exercise).	19
Table 1.4	^{133}Xe clearance following a 10min calf massage, infra red therapy, ice application and short wave diathermy (Wyper & McNiven, 1976).	21
Table 1.5	Comparison of studies using manual massage as a mode of recovery to decrease blood lactate concentration.	25
	MASSAGE TECHNIQUES & GENERAL MATERIALS AND METHODS	
Table 2.1	Classification of manual massage techniques	41
Table 2.2	Areas of the hand that can be used to administer manual massage	42
Table 2.3	Investigation number, duration of massage, and rational for selecting the duration of massage during the present study	47
	CHAPTER 3	
	Investigation 1	
Table 3.1	Age, height, weight and main participation sport of the 10 male subjects participating in Investigation 1.	57
Table 3.2	Randomly assigned treatment methods for each subject for subjects in Investigation 1.	57
Table 3.3	General sequence of leg massage (manual and vibratory) for prone then supine positions (total time = 30mins)	58
Table 3.4	Age, height, weight and main participation sport of the 10 male subjects participating in Investigation 2.	60
Table 3.5	Randomly assigned treatment order for each subject in Investigation 2.	60
Table 3.6	General sequence of the 10mins calf massage (manual and vibratory) during Investigation 2.	61
Table 3.7	Heart Rate Variability (time and frequency domain) response following 30mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10). Significant differences a = MM *vs* R. **Parasympathetic,**	64

	Sympathetic and Sympathovagal indicators.	
Table 3.8	Respiratory variables, oxygen uptake, carbon dioxide production, leg skin temperature, aural temperature and perception of feeling following 30mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10). All data are presented as Mean±Std apart from perception of feeling which is presented as Median±Interquartile range. Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R and ***d*** = 30mins post treatment *vs* baseline (R).	68

Investigation 2

Table 3.9	Heart Rate Variability (time and frequency domain) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10). Significant difference ***a*** = MM *vs* R. Parasympathetic, Sympathetic and Sympathovagal indicators.	70
Table 3.10	Systolic and diastolic blood pressure (mmHg) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).	72
Table 3.11	Leg skin temperature (°C) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10) Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, ***c*** = MM *vs* VM, and ***d*** = 10mins post treatment *vs* baseline.	74
Table 3.12	Aural temperature (°C) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10). Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, and ***d*** = VM 10mins post treatment *vs* baseline.	74
Table 3.13	Estimation of limb blood flow (*AU*) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).	75
Table 3.14	Calf circumference (cm) response following 10mins Rest (R), manual calf massage (MM) and Vibratory calf massage (VM) (n=10).	75
Table 3.15	Rate pressure product and LF:HFratio data pre and post 20mins head, neck and shoulder massage. Data from Delaney, Leong, Watkins & Brodie (2002).	80

CHAPTER 4 (Investigation 3)

Table 4.1	Age, height, weight, peak heart rate, $VO_{2\ max}$ and main participation sport of the 6 male subjects participating in Investigation 3.	94
Table 4.2	Randomly assigned recovery methods for each subject during Investigation 3.	94
Table 4.3	General sequence of the 20min calf massage (manual and vibration) for prone then supine positions during Investigation 3.	95
Table 4.4	Measurements taken at each time point during Investigation 3.	96
Table 4.5	Heart Rate Variability (time and frequency domain) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = MM *vs* R, and ***b*** = VM *vs* R. Parasympathetic, Sympathetic and Sympathovagal indicators.	99
Table 4.6	Estimation of limb blood flow response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), 20mins Manual leg Massage (MM) and 20mins Vibratory leg Massage (VM) (n=6). Significant differences	104

	(p<0.05) ***d*** = Baseline *vs* Post Exercise.	
Table 4.7	Calf circumference response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), 20mins Manual leg Massage (MM) and 20mins Vibratory leg Massage (VM) (n=6). Significant differences ***d*** = Baseline *vs* Post Exercise.	104

CHAPTER 5 (Investigation 4)

Table 5.1	Age, height, weight and main participation sport of the 10 male subjects participating in Investigation 5.	116
Table 5.2	Randomly assigned recovery methods for each subject during Investigation 5.	116
Table 5.3	Investigation 4: General sequence of leg massage (manual and vibratory) for prone then supine positions for continuous recovery (total time = 45mins).	118
Table 5.4	Measurements taken at each time point during Investigation 4.	120
Table 5.5	Mean power outputs ($W \cdot Kg^{-1}$) for the seven conditions.	121
Table 5.6a	Respiratory variables for CE at baseline, during warm up, and on completion of a bout of maximal intensity exercise cont'd.. (n = 10).	131
Table 5.6b	Respiratory variables following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R) ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE *vs* VM+VM, ***c*** = CE+CE *vs* R+R, and ***d*** = MM+MM *vs* R+R (n = 10).	131
Table 5.7a	Respiratory variables for CE following a bout of maximal intensity exercise (n = 10). Change in recovery method following 15mins cycling exercise.	132
Table 5.7b	Respiratory variables following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+CE *vs* CE+R, ***b*** = CE+CE *vs* MM+MM, ***c*** = CE+CE *vs* CE+R, and ***d*** = CE+MM *vs* CE+R (n = 10).	132
Table 5.8	Leg temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = MM+MM *vs* CE+CE (During), ***b*** = MM+MM *vs* R+R (During), ***c*** = MM+MM *vs* R+R (Post), ***d*** = VM+VM *vs* CE+CE (During), ***e*** = VM+VM *vs* R+R (During) and ***f*** = VM+VM *vs* R+R (Post) (n = 10).	136
Table 5.9	Leg temperature (°C) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+MM *vs* CE+CE (During), ***b*** = CE+MM *vs* CE+R (During), ***c*** = CE+MM *vs* CE+R (Post), ***d*** = CE+VM *vs* CE+CE (During), ***e*** = CE+VM *vs* CE+R (During) and ***f*** = CE+VM *vs* CE+R (Post) (p<0.05) (n = 10).	1136
Table 5.10	Correlation coefficient (r^2) between blood lactate, perception of feeling and diastolic blood pressure comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R) (n = 10).	140
Table 5.11	Correlation coefficient (r^2) between Blood lactate and Perception of Feeling;	141

	and Perception of Feeling and Diastolic blood pressure for combined recovery (15mins Cycling Exercise + 30mins Manual leg Massage (CE+MM), (15mins Cycling Exercise + 30mins Vibratory leg Massage (CE+VM) and (15mins Cycling Exercise + 30mins Supine Rest (CE+R)) (*n* = 10).	

CHAPTER 6 (Investigation 5)

Table 6.1	Age, height, weight, 1 repetition maximum and main participation sport of the 30 male subjects participating in Investigation 5.	162
Table 6.2	General sequence of arm massage (manual and vibratory) (total time = 8mins).	165
Table 6.3	Measurements taken at each time point	166
Table 6.4	Heart rate, blood pressure and rate pressure product response for rest, manual arm massage and vibratory arm massage prior to and following a bout of eccentric exercise (*n* = 30).	169
Table 6.5	Blood lactate response for rest, manual arm massage and vibratory arm massage prior to and following a bout of eccentric exercise (*n* = 30). * Significant difference compare to Baseline (p<0.05).	169

APPENDIX 1

Table A1.1	Heart Rate Variability (time and frequency domain) for standing, sitting, laying on a couch and supine. **Parasympathetic**, **Sympathetic** and **Sympathovagal** indicators (*n*=20)	226
Table A1.2	Systolic blood pressure for standing, sitting, laying on a couch and supine (*n*=20)	226
Table A1.3	Rate pressure product for standing, sitting, laying on a couch and supine (*n*=20)	227

APPENDIX 2

Table A2.1	Age, height, weight, maximum heart rate and main participation sport of the five male and five female subjects participating in Investigation 4.	234
Table A2.2	Randomly assigned recovery methods for each subject during Investigation 4.	234
Table A2.3	General sequence of the leg massage (manual and vibratory) for prone then supine positions (total time = 30mins).	235
Table A2.4	Measurements taken at each time point	236
Table A2.5	Respiratory variables following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R) (*n* = 10). Significant differences ***a*** = CE *vs* MM, ***b*** = CE *vs* R and ***c*** = MM *vs* R (*n* = 10).	245
Table A2.6	Leg temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences *a* = CE *vs* MM and *c* = MM *vs* R (*n* = 10).	248
Table A2.7	Correlation analysis (r^2) between Blood lactate and Perception of Feeling; and Perception of Feeling and Diastolic blood pressure for 30mins recumbent Cycling Exercise (CE), Manual leg Massage (MM) and Rest (R).	250

APPENDIX 3

Table A3.1 The effect of controlled breathing (CB) (0.20±0.0Hz) and spontaneous breathing (SB) (0.20±0.9Hz) on heart rate, LF norm, LF:HF Ratio, HF norm, RMSSD and pNN50. Data presented as the mean±SD (n = 18). **Parasympathetic**, **Sympathetic** and **Sympathovagal** indicators. 255

ABBREVIATIONS

%HR$_{max}$	Percentage of maximum heart rate
^{133}Xe	Xenon 133
1RM	One repetition maximum
ANOVA	Analysis of variance
AU	Arbitrary units
Aural$_{Temp}$	Aural temperature (°C)
a-v O_2 diff	Arterial-venous oxygen difference
BLa	Blood Lactate (mmol . l^{-1})
BPM	Beats per minute
CC	Calf circumference (mm)
CE	Cycling exercise recovery
CE+CE	15mins of cycling exercise, followed by a further 30mins cycling exercise
CE+MM	15mins of cycling exercise, followed by 30mins manual leg massage
CE+R	15mins of cycling exercise, followed by 30mins Rest
CE+VM	15mins of cycling exercise, followed by 30mins vibratory leg massage
CK	Creatine Kinase (U/L)
DBP	Diastolic Blood Pressure (mmHg)
DOMS	Delayed Onset of Muscle Soreness
EE	Eccentric exercise
FFT	Fast fourier transform
HF	High frequency band (0.15±0.4 Hz)
Hfnorm	Normalised high frequency (High Freq.÷(Total Power-Very Low Freq.)x100)
HR	Heart rate (bpm)
HRV	Heart Rate Variability
Hz	Hertz
IQR	Interquartile range
Kg	kilograms
LBF	Limb blood flow (AU)
LC	Limb circumference (mm)
Leg$_{Temp}$	Leg skin temperature (°C)

LF	Low frequency band (0.04±0.15 Hz)
LFnorm	Normalised low frequency (Low Freq.÷(Total Power-Very Low Freq.)x100)
min(s)	minute(s)
ml · min · kg^{-1}	millilitres per minute per kilogram of bodyweight
MM	Manual Massage
mmol · l^{-1}	millimoles per litre
MS	Muscle strength
pNN50	The number of adjacent pairs of R-R intervals differing by more than 50ms divided by the total number of R-R intervals
PoF	Perception of Feeling
PoP	Perception of Pain
PSD	Power spectral density
PV	Pulmonary ventilation
R	Rest
RER	Respiratory exchange ratio
RMSSD	The square root of the mean of the sum of the squares of differences between adjacent R-R intervals
RPE	Rating of Perceived Exertion
RPM	Revolutions per minute
RPP	Rate pressure product (HRxSBP)
RPS	Revolutions per second
RR	Respiratory rate
SBP	Systolic Blood Pressure (mmHg)
SD	Standard deviation
TP	Total power is the sum of the power contained within the VLF, LF and HF frequency bands.
$\dot{V}CO_2$	Carbon dioxide output
VLF	Very low frequency (VLF) band 0.00±0.04 Hz
VM	Vibratory Massage
VO_2	Oxygen uptake
V_T	Tidal volume
WAnT	Wingate Anaerobic Test
WBV	Whole body vibration

CHAPTER 1

INTRODUCTION &
REVIEW OF LITERATURE

1.1 Overview

To gain the most from any training regime, the cardiorespiratory and musculoskeletal systems must be stressed sufficiently to function in an improved way. However, Meeusen *et al.*, (2006) indicate that there is a fine line between stress and distress, and athletes are in danger of slipping from peak performance to a state of overtraining. It is therefore imperative that coaches include adequate restoration periods in an athlete's training programme to promote full short and long term recovery.

Recovery does not exclusively indicate having adequate rest, but in addition, using proven recovery methods (Cosca & Navazio, 2007); which include incorporating rest days; alternating hard and easy training sessions; working on a different aspect of fitness on alternative days; and receiving massage therapy (Morsaka, 2005; and Ronglan, Raastad & Børgesen; 2006). Thus, it follows that any technique which has the ability to assist with recovery and thus increase the capacity to train for longer, is of use to athletes of all abilities.

Over the last few decades, massage therapy has re-emerged as one such recovery method which purports to hasten recovery from exercise. A regular massage regime is now considered by many coaches and elite athletes to be as an integral part of any structured training programme, as is a warming up, and sufficient or complete rest. Moreover, a massage therapist is now considered as valuable a commodity to an elite athlete as a physiotherapist, nutritionist, conditioning specialist and medical doctor (Archer, 2006).

1.2 A brief history of massage

Massage is a primitive and innate form of therapy widely used by humans for millennia, yet mostly it remains an ancient therapeutic art which has very little scientific foundation. Reference has been made to massage in literature, poetry and pictorial form for at least 3000 years (Moyer, Rounds & Hannum, 2004), with the oldest medical textbook by Nei Ching detailing the types and use of massage in 2760BC (Goats, 1994). This use continued, and was described in detail by Hippocrates, Galen, Avicenna, de Chauline and Parc (Goldstone, 1999; Goldstone, 2000; Calvert, 2002a; and Ernst, 2003); with all describing massage as an effective therapy for ailments such as war battle injuries (Goats, 1994), neuralgia and headaches (DeDominico, 2007).

Although there is very little evidence that massage was used in prehistoric times (DeDomenico, 2007), it is clear from observing primate behaviour that self/group grooming and touch are a very important part of group bonding. These altruistic actions are not identical to latter day therapeutic massage, it does give an indication and insight into behaviour which has pervaded since the development of early civilisation (Calvert, 2002a).

The word massage has its origins from the French words *masser* and *massage*, which are in all probability derived from four ancient languages, namely Arabic ('*mash*' (to touch, stroke or anoint)), Greek ('*massein*' (to knead)), Hebrew ('*mashesh*' (to press softly)) and Latin ('*manus*' (hand)) (Bell (1964), Cafarelli & Flint (1992) and DeDomenico (2007)). Bell (1964) also lists other words used for massage from Tonga and Hawaii, these being '*toogi toogi*' (to beat) and '*lomi-lomi*' (to rub, press or squeeze) respectively.

Perhaps the most important figure in the development of modern day massage was Per Hernik Ling (Calvert, 2002), who classified the five elements of 'Swedish' massage (effleurage, petrissage, friction, tapotment and vibration) in 1813 (Benjamin, 1993). Estradere furthered the reputation and use of massage in 1863 with the publication of *Du Massage* (DeDominico, 2007), with this text classifying massage techniques, and how each affects the body's physiological and mechanical systems (Fassett, 1904). This tradition of classification and description has continued to the present day, with many treatise published classifying and describing modern massage techniques (Ylinen & Cash, 1995; Cash, 1996; Watt, 1999; Caldwell, 2003, and DeDominico, 2007)

Despite the classification of massage as a new complementary therapy in the UK, manual massage has been a recognised form of medical treatment since the late 19th centaury (Goats, 1994). In the face of the inevitable, but unavoidable links between massage and prostitution (Nicholls & Cheek, 2006), the practice maintained its respectability by establishing the Society of Trained Masseuses in 1894 (Bell, 1964).

This society eventually merged with the Institute of Massage and Remedial Exercises, and gained the Royal Charter becoming the Chartered Society of Massage and Medical Gymnastics (CSMMG) in 1920 (DeDominico, 2007).

During World War 1, massage was extensively used as a recuperative therapy for the treatment of battle injuries (Clayton, 1915); and testament to this was the Department of Massage set up by St. Thomas Hospital (London) to treat injured soldiers (King's College London Achieves, 2005). However, during World War 2 its use declined due to the emergence of new therapeutic machines and pharmacological interventions (Callaghan, 1993). The decline of massage continued, and in 1943 the CSMMG changed its name to the Chartered Society of Physiotherapy (DeDominico, 2007). Despite this name change, and the relegation of massage as a medically recognised rehabilitation therapy, massage remains the central expertise of physiotherapists (Goldstone, 1999), and an important therapeutic modality for use with athletes, and within the medical profession.

1.3 Classification of the massage type used during the study, and the proposed physiological and psychological effects of massage on the human body

1.3.1 Type and classification of massage: Cafarelli & Flint (1992) defined massage as "a mechanical manipulation of the body tissues with rhythmical pressure and stroking for the purpose of promoting health, and also well-being". Therefore, from the outset it was of paramount importance to select the correct type of massage for the study in order to maximise the recovery from the exercise bouts.

The two main classifications of massage considered for the study where therapeutic and relaxation massage. Therapeutic massage (TM) is defined by Cassar (2004) as the treatment or attempted cure of a disorder or disease, by restorative, remedial and curative means. As the study was not focused on the treatment of medical disorders (e.g. chronic lower back pain, fibromyalgia etc.) or treat disease (e.g. Parkinson's - Hernandez-Reif, 2002; or Arthritis, Field, Diego, Hernandez-Reif & Shea, 2007). As this was not the aim of the massage administered during the present study, it was discounted.

The massage type which was used during the study is defined by Sherman, Dixon, Thompson & Cherkin (2006) as relaxation massage. Relaxation massage is the generic term to describe the basic strokes of massage proposed by Ling (Calvert, 2002) (i.e. effleurage, petrissage, vibration etc.), whose aim is to promote recovery by moving body fluids, removing waste from cells, relaxing muscle and diminishing pain. Therefore, as the proposed effects of this type of massage fit the aims of the study, it may maximise recovery from exercise and therefore was used during the five investigations in the study.

1.3.2 Physiological and Psychological effects: The pushing, pressing, kneading, squeezing and rubbing of the hand or vibratory massage adaptor upon the skin are all fundamental massage techniques which have a mobilising effect on the skin's surface, subcutaneous tissue and underlying muscle. These repeated mechanical actions of massage (manual and vibratory) may well result in a variety of physiological and psychological responses, which are summarised in Table 1.1 (Stamford, 1985; Cafarelli, Sim, Carolan & Liebsman, 1990; Morsaka, 2005; Weerapong, Hume & Kolt, 2005; DeDomenico, 2007; and G5® Europe website, 2008), However, there are inconsistencies and lack of consensus evident in the literature when attempting to elucidate the short term effects of massage techniques when administered at rest, or during recovery from exercise. Furthermore, other than the anecdotal statements regarding the efficacy of vibratory massage there is very little empirical research to substantiate these claims, and there has been no direct comparison between techniques regarding the potential benefits of manual and vibratory techniques when measuring these parameters

Table 1.1 Physiological and psychological effects of manual and vibratory massage (Stamford, 1985; Cafarelli, Sim, Carolan & Liebsman, 1990; Morsaka, 2005; Weerapong, Hume & Kolt, 2005; DeDomenico, 2007; and G5® Europe website, 2008).

Physiological effects of massage	Psychological effects of massage
1. Causes an alteration in the autonomic nervous system by increasing parasympathetic activity, thus decreasing heart rate **2.** Decreases cardiovascular parameters (blood pressure and rate pressure product) **3.** Increases metabolic rate **4.** Causes a decrease in respiratory rate **5.** Increases limb circulation **6.** Rapidly eliminates lactate following intense exercise **7.** Decreases the indices of acute muscle damage (creatine kinase release and pain) **8.** Promotes acute injury healing (removal of oedema and recovery of muscle strength)	**1.** Pain relief **2.** Promotes physical relaxation and relieves anxiety and tension (stress) **3.** Promotes a general feeling of well-being

In the following sections, a review of the literature base focussing on the proposed physiological and psychological effects on massage is presented. It should be noted that the vast majority of previous studies refer specifically to manual massage techniques, and a comparative analysis of the two massage modes (manual and vibratory) has yet to be fully investigated. Each physiological effect of massage will be dealt with in order as it is presented in the Table 1.1.

1.4 The effect of massage on cardiac autonomic activity, with specific reference to alterations in heart rate and heart rate variability

The autonomic nervous system has been implied as one of the mechanisms by which therapeutic massage achieves its results. Until now, this effect has been inferred from the indirect effects of massage on heart rate and blood pressure. Massage has been reported previously to lower heart rate and blood pressure (Barr & Taslitz, 1970; and Longworth, 1982; Delaney, Leong, Watkins & Brodie, 2002; and Aourell, Skoog & Carlson, 2005), and increase perceived feeling of relaxation, and decrease stress and tension (Wilkinson, Aldridge, Salmon, Cain & Wilson, 1999; Delaney & Brodie, 2000; and Billhult & Dahlberg, 2001). Despite an extensive literature search there appears to be only two other studies which have directly measured cardiac autonomic activity by assessing the influence of massage on the sympathetic and parasympathetic nervous system during massage (Delaney, Leong, Watkins & Brodie, 2002; and McNamara, Burnham, Smith & Carroll, 2003). This method of assessing cardiac autonomic activity is conventionally know as heart rate variability (HRV) (vanRavenswaaji-Arts, Kollée, Hopman, Stoelinga & Geijn, 1993).

Heart rate variability (HRV) is the measure of the beat by beat fluctuations of the heart rate around its central mean. These variations in heart rate are as a direct result of interplay between the sympathetic and parasympathetic constituents of the autonomic nervous system (TaskForce 1996). The cardiac pacemaker (sino atrial node) is controlled by the parasympathetic and sympathetic systems, and the interplay between these two components directly affects the variation in the time period separating successive heart beats (peak of the QRS).

Observance and diagnosis from cardiac cycle length (R-R variation) have been used for many years, and are utilised for both diagnostic and prognostic purposes (Prober, Braun & Freedson, 2004; and Winsley, Armstrong, Bywater & Fawkner, 2003). Hon & Lee (1965) observed alterations in the inter-beat intervals in distressed foetuses; and when the foetuses became distressed, there was a significant decrease in the variation in inter-beat interval. Initial research to investigate cardiac autonomic control used propranolol and atropine (dual blockade system) in order to respectively abolish the parasympathetic and sympathetic influences on the heart. The two major limitations of this method are that it only allows the assessment of either parasympathetic or sympathetic at any one time, and therefore does not allow the monitoring of the synergistic sympathovagal drive of the heart (Kotama, McLean, Dighron & Guz, 1982; and Brenner, Thomas & Shephard, 1997). Therefore, its use as an inclusive system to monitor cardiac autonomic drive is limited. The second limitation is that the method is highly invasive.

With the advent of new software for the analysis of R-R intervals within the last 25 years (Chandenra, Yeates & Hong, 2003), HRV is now considered a non-invasive, sensitive and indirect method for assessing both health and disease states within research and clinical settings (Delaney, Leong, Watkins & Brodie, 2002). During diseased states such as diabetes mellitus, and following myocardial infarction (Liao, Evans & Chambles, 1997), or during periods of psychological, emotional (Delaney & Brodie, 2000) or heat stress (Bruce-Low, Cotterrell & Jones, 2006) there is an increase in sympathetic activity and a decrease in parasympathetic activity, and consequently a significant reduction in variability (Sloan *et al.*, 1994). In addition, other physiological factors can affect HRV, including:-

- <u>Age</u> (Aging causes deterioration in cardiac autonomic function, which is prompted by a decrease in sinoatrial node responsiveness and afferent neural conduction (Bennemeier *et al.*, 2003))
- <u>Gender</u> (At rest females have been shown to have lower sympathetic activity than males (Sullivan & Fowlkes, 1996)),
- <u>Posture</u> (See Appendix 1),
- <u>Time of day</u> (Circadian variations have been reported in HRV (Malliani, Pagani, Lombardi & Cerutti, 1991; and Kondo, Matsubara, Nakamura & Hotta, 2002))

HRV is commonly measured for 24hrs using a Holter recording electrocardiogram (Sinnreich *et al.*, 1998); however, such lengthy measures are not always feasible, and methods to suit particular research designs are required. One such system is the Polar 810*i* data logger and analysis software (Polar, Kempele, Sweden). This telemetric system is non-invasive requiring the use of a simple transmitter belt; and therefore negates the need for leads and direct wiring (Delaney, Leong & Brodie, 2000 and Akselrod *et al.*, 1985). This system can be used for short term measurements of between 2 - 15mins, and the method has been shown to correlate highly with 24hr ECG Holter recordings in all variables of the frequency and time domain (Bigger, Fleiss, Rolnitzky, Steinman, 1993; and Delaney Leong & Brodie, 2001). Furthermore, a preliminary study investigating the test-retest reliability of the Polar system is presented in Appendix 1, and demonstrates that this method is a reliable measure of time and frequency domain HRV in healthy adult males under the laboratory conditions in the present study.

The minimum preferred short-term measurement time for reliable and valid time and frequency domain measures is 5mins (TaskForce, 1996), provided that the heart rate is stable. Initial concerns regarding the stability, reproducibility and interpretation of short term HRV recordings have proved to be unfounded (Hohnloser *et al.*, 1992). The TaskForce (1996) have since validated the use of short term recording and suggest that the R-R data can provide a good indication of sympathovagal balance for research purposes. Winsley, Armstrong, Bywater & Fawkner (2003), Højgaard, Holstein-Rathlou, Agner & Kanters (2005), and Kobayashi (2007) all state that the large deviation in the mean is due to large inter-subject variability; however, if subjects are instructed correctly and controlled appropriately during measurement, intra-subject test retest HRV variability during a 5min recording can be negligible (TaskForce, 1996).

Following the collection of R-R data, HRV can be calculated after the removal of any abnormal beats. With the Polar system, the R-R data is edited and outliers removed using both an automatic filter as well as manually using the 'Error Correction' function within the Polar Precision Performance software. The current methodology used to analyse HRV are time and frequency domain. Time domain assesses the autonomic modulation of the cardiac cycle; and frequency domain analyses the spectral components of the variations in inter beat intervals (Chandenra, Yeates & Wong, 2003)

The time domain HRV measurement is the simplest method of calculating HRV and assessing the intervals between successive normal beats (R-R) (Delaney, Leong, Watkins & Brodie, 2002). Measurements of time domain HRV are heart rate (bpm), standard deviation of interbeat intervals (ms) (SD), root mean square of the successive differences (ms) (RMSSD) and number of pairs of adjacent NN intervals differing by more than 50ms (%) (pNN50). pNN50 and RMSSD are indicators of parasympathetic drive of HR (Task Force, 1996), and both variables have been shown to correlate highly with the magnitude of the vagal drive to the heart (Rimoldi *et al.*, 1990; Eckberg, 1997; and Delaney, Leong, Watkins & Brodie, 2002).

Frequency domain HRV measurement and interpretation is more complicated. The R-R data is processed by autoregression analysis and grouped into three separate frequency components using power spectral density analysis (Eckberg, 1997). The components are very low frequency (VLF), low frequency (LF) and high frequency (HF); with total power (TP) being the sum of all three individual components. The autoregressive model produces an accurate estimation of spectral components even on a small number of inter-beat intervals (commonly 5mins) (TaskForce, 1996).

Figures 1.1*a* & *b* show the effect of heat stress placed upon the body, in order to decrease parasympathetic and increase sympathetic activity. Power spectral density (PSD) graphs show frequency domain data, analysed using fast fourier transform (FFT) analysis during two different heat exposures (Bruce-Low, Cotterrell & Jones, 2006). These PSD graphs show data for a subject in the last 5mins of 10mins in thermoneutral conditions (27.0±0.7°C) (*a*), and during the last 5mins of a 15mins dry sauna exposure (74.3±5.9°C). Figure 1.1*a* (in thermoneutral conditions with an average HR of 75bpm) clearly shows the areas on the graphs that are represented by the VLF, LF and HF frequencies and are depicted by the different lines (refer to the key). Figure 1.1*b* (during sauna heat exposure with a HR of 135bpm) clearly shows the reduction in the HRV components (reduction in overall power and thus HRV). Power is represented by the area under the PSD graph, so when exposed to the sauna there is a reduction in the area under the graph, thus representing a reduction in overall total power.

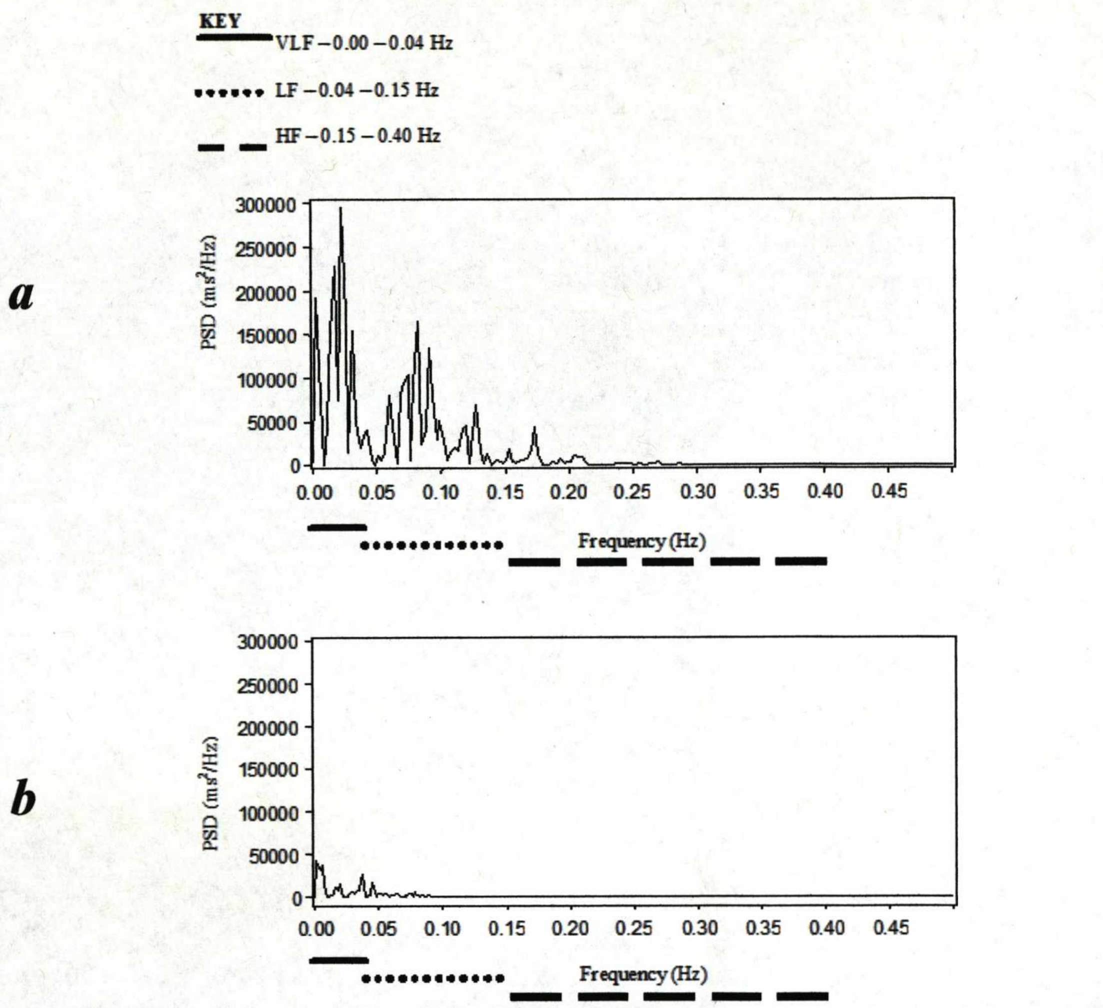


Figure 1.1*a&b* The distribution of power within the HRV components. The areas on the graphs that are represented by the VLF, LF, and HF frequencies are depicted by the different lines (refer to the key). ***a)*** A representative 5min sample taken after 10mins of seated rest prior to sauna exposure using the fast fourier method of obtaining a power spectral density graph in thermoneutral conditions (room temperature maintained at 27±0.7°C; HR 75bpm). ***b)*** A 5min sample obtained during the final 5mins of a 15min sauna exposure using the fast fourier method of obtaining a power spectral density graph (74.3±5.9°C; HR 135bpm). Data from Bruce-Low, Cotterrell & Jones (2006).

Furthermore, the two branches of the autonomic nervous system (sympathetic (LF) and parasympathetic (HF)) may be distinguished by normalising the two frequencies. This calculation minimises the effect of changes in total power and removes the influence of VLF. VLF is thought to reflect blood pressure regulation (Akselrod *et al.*, 1985) and thermoregulation (TaskForce, 1996); however VLF is not well defined, and it is recommended that the component be removed from the interpretation of short term recording (~5mins) (TaskForce, 1996; and Tarkiainen *et al.*, 2005). Adhering to these recommendations, TP and VLF have not been used in the present investigation. Normalised LF and HF are calculated as LFnorm (Low

Freq.÷(Total Power–Very Low Freq.)x100) and HFnorm (High Freq.÷(Total Power–Very Low Freq.)x100). Finally, to estimate sympathovagal balance, a ratio of LF:HF is calculated from absolute units (Dishman *et al.*, 2000). For the purposes of this investigation, frequency domain HRV will be reported as LFnorm, HFnorm and LF:HF ratio.

Research by Pomeranz *et al.*, (1985) has shown that following the administration of propranolol LF is reduced, signifying that LF can be used as an indicator of sympathetic drive (Rimoldi *et al.*, 1990; and Malliani *et al.*, 1991). Moreover, research by Rimoldi *et al.*, (1990) and Bernardi *et al.*, (1995) has shown that following the administration of atropine HF disappeared, demonstrating that HF is an indicator of parasympathetic drive (Rimoldi *et al.*, 1990; and Pomeranz, *et al*, 1985).

Delaney, Leong, Watkins & Brodie (2002) compared massage with passive rest using 30 subjects. HRV was measured using the Polar R-R monitor. Following a 20min massage to the head, neck and shoulders there was a significant decrease in heart rate, systolic blood pressure and indicators of sympathetic drive (Table 1.2); and a significant increase in parasympathetic activity. The authors concluded that in normal healthy subjects, massage was effective at altering cardiac autonomic activity.

Table 1.2 Effect pre- and post- 20min neck, shoulder and back massage on heart rate, blood pressure and sympathovagal balance (Delaney, Leong, Watkins & Brodie, 2002) (Mean±SE).

	Pre massage	**Post massage**
Heart rate	71.9±2.4	66.5±2.5
Systolic blood pressure	125±3.5	119±3.4
Sympathovagal balance (LF:HF ratio)	1.52±0.28	1.26±0.26

McNamara, Burnham, Smith & Carroll (2003) administered a 20min back massage prior to diagnostic cardiac catheterisation in 46 subjects, and the subjects were divided equally into a treatment or control group. HRV was measured using a standard 12-lead ECG, and the authors measured high frequency (HF) values as an indication of cardiac autonomic alteration. Following the 20min massage, systolic and diastolic pressure was reduced when compared to rest, indicating a greater parasympathetic effect. Conversely, massage had no effect on heart rate. They stated that, despite some positive results, the results were inconclusive.

Other complementary therapies have been shown to be effective at increasing overall HRV, reflecting an increase in parasympathetic drive of heart rate. Numerous studies have reported the effects of acupuncture at altering sympathovagal balance (Moffet, 2006 and Sparrow, 2007). Haker, Egekvist Bjerring (2000) concluded that acupuncture induced a significant increase in the vagal component, and decrease in the sympathetic component of heart rate variability thus reflecting greater parasympathetic activity; which in the view of the authors went some way to explain why the 10 subjects in the study were psychologically more relaxed. This conclusion was confirmed by Li, Wang, Mak & Chow (2005) and Huang *et al.*, (2005) who concluded that acupuncture suppressed sympathetic and enhanced vagal activity, which lowered blood pressure and heart rate.

1.5 Effect of massage on the cardiovascular system (blood pressure and rate pressure product)

The changes in sympathovagal balance not only affect heart rate and HRV parameters, but also affect blood pressure and rate pressure product (HR x SBP) (Kowalewski & Urban, 2004).

1.5.1 Blood pressure: Aourell, Skoog & Carleson (2005) reported that following 30mins of back, neck and chest massage in 16 healthy normotensive males, SBP decreased significantly from 139.9±15.5mmHg to 133.5±11.2mmHg. The longitudinal study also massaged subjects twice a week for 12wks; and by the end of the last massage session, mean SBP was significantly lower (pre 130.3±14.6mmHg; end 123.7±11.3mmHg). Delaney, Leong, Watkins & Brodie (2002) administered a 20min massage to the head, neck and shoulders and reported that SBP decreased significantly from 125±3.5mmHg to 119±3.4mmHg.

Fakouri & Jones (1987) administered a 3min slow stroke back massage, and reported a significant decrease in SBP. However, using a similar protocol and similar population type (elderly care home patients) Corley, Ferriter, Zeh & Gifford (1995) reported no effect.

Other studies have administered massage following a period of exercise and report no effect. Hinds *et al.*, (2004) administered a 12min leg massage following exercise, and reported that there was no significant difference in SBP between massage and the control rest group (pre massage 124±10mmHg; post massage 126±8mmHg). Similarly, a preliminary study conducted by Jones, Cotterrell, Froom, Gammon & Bruce-Low (2004) showed that a leg massage following a maximal intensity bout has no significant effect on SBP compared to Rest.

Cambron, Dexheimer & Coe (2006) suggest that this varied effect is common as the type, location, duration and intensity of massage has an effect on blood pressure. Vigorous sports massage or trigger point massage is associated with an increase in SBP, while slow effleurage is associated with an average decrease of 1.8mmHg (in 150 normotensive adults).

1.5.2 Rate pressure product: Rate pressure product is a rate pressure index, and a reflection of myocardial oxygen uptake (Campbell & Langston, 1995; Campbell, Langston & Ross, 1997; and Herminda *et al.*, 2005). However, despite being a simple index (HR x SBP) no other massage investigations have reported this result. Therefore HR and SBP data reported in other similar studies has been calculated, and the effect of massage is equivocal.

Extrapolation on data reported by Delaney, Leong, Watkins & Brodie (2002) shows that RPP decreased from 8987.5units to 7913.5units (an 11.85% decrease) for massage, compared to a 4.57% decrease for rest. There was a similar effect reported by McNamara, Burnham, Smith & Carroll (2003) where RPP decreased 15.6% during massage compared to a 7.3% decrease for rest. Conversely, data from Hinds *et al.*, (2004) showed that during massage RPP increased from 7812units to 9828units (up 20.5%) compared to a 16.23% increase for rest. Therefore, it appears that there are no common effect of massage on RPP.

1.6 The effect of massage on oxygen uptake and carbon dioxide output

The effect of massage on resting metabolic rate (oxygen uptake and carbon dioxide production) has been investigated over many years, from Cuthbertson (1932 and

1933) to Boone, Tanner & Radosevich (2001). Despite the definitive claims by massage and complementary therapy websites that massage increases metabolic rate, very few studies provide evidence to support this effect. The studies appear to be contradictory, indicating no change in metabolic rate (Boone, Cooper & Thompson, 1991). Other research has reported decreases (Lahart, Milmouni, Ashbel, & Dollberg, 2007), as well as some showing increases (Pocklington & Reprovich, 2002). Furthermore, there is paucity of empirical research data regarding any alteration in metabolic rate caused by vibratory massage.

In this respect, for the purposes of this present investigation the effect of massage on metabolic rate was determined by the indirect calorimetry through measuring oxygen uptake and carbon dioxide output.

Early work by Cutherbertson (1932 and 1933) reported that massage produced a mixed effect. Following a vigorous 10min massage of the legs, the oxygen uptake (VO_2) for one subject increased by 34%, with another subject's values remaining unaffected. The overall conclusion for the study was that massage had very little effect or no effect on metabolic rate. Similarly, Boone, Cooper & Thompson (1991) report that a 30min massage applied prior to a 10min submaximal treadmill run (80%HR_{max}) had no effect on oxygen uptake compared to rest either during the massage, or during the subsequent exercise bout. A further investigation by Boone & Cooper (1995) reported that there was no significant difference in oxygen uptake between the massage and passive rest groups, indicating that massage had no effect on metabolic rate. Furthermore, they reported that there was a slight but insignificant difference in HR and cardiac output, but no change in arteriovenous oxygen difference (a-vO_2 diff) or pulmonary ventilation.

Conversely Boone, Tanner & Radosevich (2001) report an 11% decrease in VO_2 following a 10min back massage, compared to baseline. In order to clarify that this response was not merely a function of postural relaxation, the results were compared to 10mins of no treatment in the same position. In this position with no massage, VO_2 did not decrease. The authors concluded that the back massage appeared to relax the subjects to a greater degree than merely laying at rest. In a study investigating the effect of massage on premature infants, Lahart, Mimouni, Ashbel,

& Dollberg (2007) concluded that five days of back massage therapy administered to five premature enterally fed infants decreased their metabolic rate. They compared the results with five age and weight matched infants. Both groups were fed a similar diet throughout the trial period, and the infants in the massage group had significantly lower energy expenditure (59.6±3.6Kcal/Kg/24hours) compared to the control group (63.1±5.4Kcal/Kg/24hours). This decrease in metabolic rate has consistently been reported by other similar infant studies (Field *et al.*, 1986; Scafidi *et al.*, 1990; Scafidi, Field & Schanberg, 1993; De-Roiste & Bushnell, 1996; and Ferber *et al.*, 2002), and accounts for the enhanced weight gain in premature infants.

In contradiction, Pocklington & Reprovich (2002) noted a significant increase in oxygen uptake following a 60min full body massage encompassing the back, posterior legs, head, neck and shoulders, arms, abdomen, anterior legs, and feet. The oxygen uptake, which was used as a measure of metabolic rate, increased significantly to $3.81\text{ml} \cdot \text{kg} \cdot \text{min}^{-1}$ compared to passive rest ($2.93\text{ml} \cdot \text{kg} \cdot \text{min}^{-1}$). They concluded that massage had a significant increase on metabolic rate compared to passive rest, although they did not suggest a reason why this occurred.

Furthermore, Gupta, Goswami, Sadhukhan & Mathur (1996) measured oxygen uptake following multiple 1min bouts of supra maximal cycle exercise in 10 male subjects. They administered the leg massage for 10mins post exercise and observed that oxygen uptake remained above that of passive rest recovery for 30mins post massage; and was also above the baseline value at this same time point. The conclusion by Gupta, Goswami, Sadhukhan & Mathur (1996) was that the increased oxygen uptake seen during massage may have been due to increased muscle temperature caused by the friction between the hand of the therapist and the skin of the subject. However, as suggested by Drust *et al.*, (2003) and Hinds *et al.*, (2004), massage of the skin does not appear to cause a significant increase in muscle temperature, and therefore the explanation by Gupta, Goswami, Sadhukhan & Mathur (1996) may be incorrect.

With regards to the effect of vibratory massage on metabolic rate, there is a growing body of evidence regarding the effect of whole body or limb vibration; and how this method can affect the physiological and mechanical systems of the body (Erskine, Smille, Leiper, Feldman, Ball & Cardinal, 2007). Cardinale & Lim (2003) hypothesised that vibratory massage may increase oxygen extraction (a-vO_2 diff) leading to an increased oxygen uptake, providing carbon dioxide output decrease in proportion, however, no mechanism was suggested. Rittweger, Schiessel & Felsenberg (2001) investigated the effects of a 3min whole body vibration at 26Hz on oxygen uptake and subsequently compared the results with mild resistance exercise. This study suggested that vibration increased oxygen uptake by 4.5ml $\cdot$ min $\cdot$ kg^{-1} above that of the value for mild exercise, and the authors concluded that the increase in VO_2 was a direct result of vibration increasing muscular activity. However, as they did not present electromyography data to support this assumption the results remain speculative.

1.7 The effect of massage on respiration (pulmonary ventilation, respiratory rate and tidal volume)

Along with the measures of sympathovagal balance, respiratory rate (RR) is considered to give an indirect indication of relaxation in conscious healthy adults (DeDomenico, 2007), as a state of relaxation has been shown to decrease breathing frequency (Gallios, 1984; and McRee, Noble & Pasvogal, 2003).

In relation to massage and respiratory rate, Hayes & Cox (1999) reported that in a study using 25 subjects (mean age 53.9years), in addition to a decrease in HR & SBP during a 5min foot massage, there was a concomitant decrease in RR from 23.04±6.22 to 20.97±5.71cycles $\cdot$ min^{-1}. In addition, Stevenson (1994) administered a 20min foot massage, and observed a decrease in RR of 1.56 breaths per min, compared to a decrease of 0.12 in the control passive rest group. This was coupled with a mean decrease in HR of 1.6bpm for the massage group, and Stevenson (1994) concluded that the decrease in RR was unexpected, but did not state a reason why this may be the case.

A more recent study by Okvat, Oz, Ting & Namerow (2002) also reported a decrease in effect on RR, showing a significant decrease from 16.3 to 15.3cycles $\cdot$ min^{-1} following a 10min massage of the arm, shoulder, and neck.

Despite the aforementioned studies reporting that an alteration in RR was evident following manual massage, the question arises regarding the effects of massage on either tidal volume or pulmonary ventilation. As such, it is not possible to ascertain whether the changes in RR are accompanied with an alteration in tidal volume, and thus ventilation; therefore, it is difficult to draw precise conclusions regarding the effect of massage on respiratory control.

There is currently no research examining the effect of mechanical vibratory massage on respiration; however, there is data from a study using manual vibratory massage. Doering *et al.*, (1999) investigated the effects of manual massage on pulmonary function in patients following coronary artery bypass surgery. The massage was performed for 15mins on the thoracic region at a frequency of 8 to 10 vibrations per second (10Hz). They reported a significant decrease in respiratory rate from a baseline of 19 to 17cycles $\cdot$ min^{-1} at the end of treatment, coupled with a significant increase in tidal volume from 0.502 to 0.602 litres $\cdot$ min^{-1}. Extrapolation of the results suggests that despite an increase, there was no significant difference in pulmonary ventilation (9.5 litres $\cdot$ min^{-1} baseline; 10.2 litres $\cdot$ min^{-1} post treatment). The authors concluded that manual vibratory massage of the thoracic region is an effective therapeutic method which induces a relaxation response.

1.8 The effect of manual and vibratory massage on limb blood flow

1.8.1 The effect of manual massage on limb blood flow

The effect of massage on blood flow has been studied sporadically for many decades, and the results of studies are often equivocal. An early study by Carrier (1922) indicated that there was an evident reaction when stroking an area of the skin, causing the underlying vessels to engorge with blood, thus causing hyperaemia of the surrounding skin. The conclusion was inferred following massage of the hand, and observed under a microscope, and indicated increased blood flow.

Pemberton (1932) concluded that massage, when applied to the legs of arthritis sufferers, aided venous return from peripheral vessels. The study concluded that massage should be considered as an effective way to increase blood flow when the long muscles of the leg (calf and quadriceps) could no longer function as a pump because there were little or no muscle contractions.

Mennell (1945) proposed a mechanism by which massage could increase blood flow. The application of massage to a limb was similar to applying pressure to a soft fluid filled tube. The application of pressure, coupled with the pushing motion will cause the fluid to flow in the direction in which the pressure is applied. Therefore, by definition the same effect may occur in a vein. Pressure applied distally moving proximally causes a vein to be emptied, creating a momentary negative pressure within the vessel, which causes blood to be drawn through the capillaries. This transient effect caused by massage relates to the muscle pump theory which has been proposed as a means by which blood flow and cardiac output may increase during exercise (Cafarelli & Flint, 1992; Laughlin, 1987; and Valic, Buckwalter & Clifford, 2005).

This research was later challenged by Wakim, Martin, Terrier, Elkins & Krusen (1949) who showed that there was no evidence of an increase in arterial and venous blood flow following massage, and therefore no definite evidence of a consistent and significant increase in total limb blood flow in any part of the body. Further studies (within the last 50 years) have also been contradictory (Table 1.3).

Table 1.3 The effects of massage on blood flow at rest and/or at rest following a bout of exercise (↔ No change; ↑ Increase) (R administered at rest; PE = at rest post exercise).

Authors	Method used to quantify changes in blood flow	Area treated	Effect of massage on blood flow	At rest (R) or post exercise (PE)
Bell (1964)	Plethysmograph	10min calf massage	↑	R
Hansen & Kristensen (1973)	^{133}Xe wash out	5min calf massage	↑	R
Hovind & Nelson (1974)	^{133}Xe wash out	6min calf massage	↑	R
Dubrovsky (1982)	^{133}Xe wash out	15-25min back and leg massage	↑	R
Mori *et al.*, (2004)	Laser blood flow meter	5min lumber massage	↑	PE
Wyper & McNiven (1976)	^{133}Xe wash out	10min calf massage	↑	R
Shoemaker, Tiddus & Mader (1997)	Doppler ultrasound	5min arm/leg massage	↔	PE
Hinds *et al.*, (2004)	Doppler ultrasound	12min quadriceps massage	↔	PE

Bell (1964) reported a doubling in limb blood flow following a 10min massage of the calf. Blood flow and volume were measured using venous occlusion plethysmography, immediately following the massage, and 40mins post treatment. Despite these results, a cautionary note is that the study only one subject (a male).

Hansen & Kristensen (1973) observed a significant increase in muscle ^{133}Xe clearance during the administration of a leg massage in 12 male subjects; which then decreased following the cessation of manual therapy. This clearance effect was accounted for by an increase in blood flow. Dubrovsky (1982) also supports the view that massage causes an increased blood flow within the skeletal muscle. Figure 1.2 demonstrates that tibialis anterior muscle circulation increased from $4.5\pm0.11ml \cdot 100g^{-1}$ up to $6.4\pm0{\cdot}11ml \cdot 100g^{-1}$ following massage, although the units of measure on the graph are do not correspond with those reported and therefore are unclear.

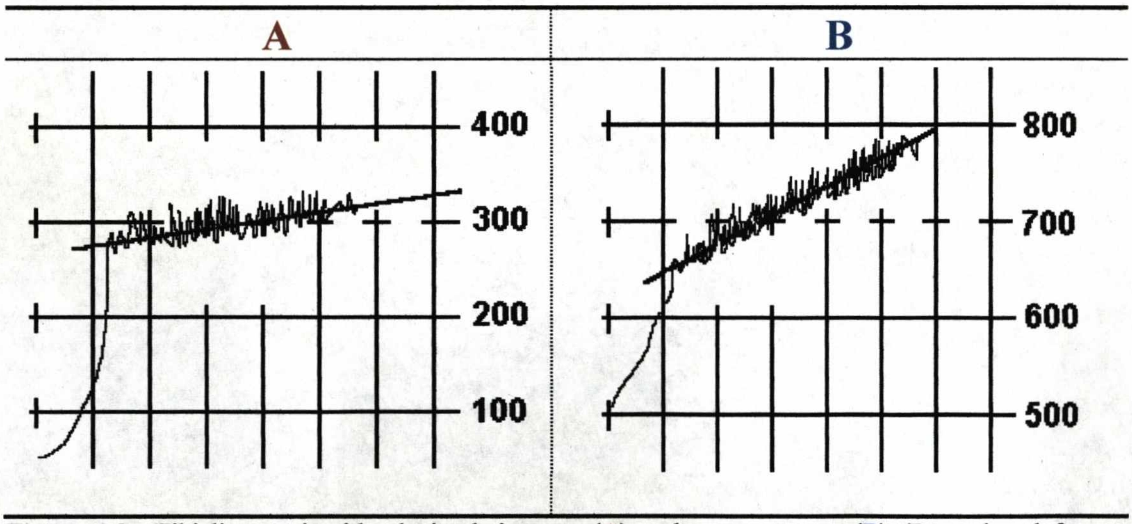


Figure 1.2 Tibialis anterior blood circulation pre (**A**) and post massage (**B**) (Reproduced from Dubrovsky, 1982).

Wyper & McNiven (1976) compared the effect of a 10min calf massage to either infra red, ice application or short wave diathermy, on blood flow (Table 1.4). Compared to the other three conditions, massage was the only method which increased ^{133}Xe clearance, indicating increased blood flow. Despite this, the authors concluded that there was no conclusively significant increase in blood flow. Similar to the data by Bell (1964), one subject in the Wyper & McNiven (1976) study had an increase in muscle blood flow of 400%. They concluded that this may have occurred because the subject had noticeably more muscle than the other seven subjects within the study. However, there is no other evidence to suggest that an increased musculature predisposes a person to have an increase in blood flow following massage.

Table 1.4 ^{133}Xe clearance following a 10min calf massage, infra red therapy, ice application and short wave diathermy (Wyper & McNiven, 1976).

Treatment type	Pre treatment	Post treatment	Change
Massage	2.0±0.7ml · 100g · min^{-1}	2.9±2.0ml · 100g · min^{-1}	↑ 0.9ml · 100g · min^{-1}
Infra red therapy	2.9±0.4ml · 100g · min^{-1}	2.4±1.1ml · 100g · min^{-1}	↓ 0.5ml · 100g · min^{-1}
Ice application	2.7±1.1ml · 100g · min^{-1}	2.5±1.8ml · 100g · min^{-1}	↓ 0.2ml · 100g · min^{-1}
Short wave diathermy	2.5ml · 100g · min^{-1}	2.4ml · 100g · min^{-1}	↓ 0.1ml · 100g · min^{-1}

Despite all the early claims of increased blood flow caused by massage, recent studies using superior methodologies dispute these claims. A study by Shoemaker, Tiidus & Mader (1997) discounted the claims made by the previous authors (Wyper & McNiven, 1976; Burovykh, Samtsova & Manuilov, 1976; and Dubrovsky, 1982) because of their methodological anomalies and difficulties in quantifying the changes in blood flow. For instance, there is a tendency for the ^{133}Xe method to overestimate blood flow due to the local hyperaemia caused by the trauma of the injection to administer the ^{133}Xe into the muscle (Hinds *et al.*, 2004). Shoemaker, Tiidus & Mader (1997), using Doppler ultrasound, observed no significant changes in mean femoral artery blood flow (for 10 subjects), at rest and during 5mins of manual massage (Figure 1.3). The results were compared to light voluntary exercise. At passive rest and prior to effleurage and petrissage massage, mean blood velocity was 9.73±0.7cm · s^{-1} and 9.38±1.0cm · s^{-1} respectively. Following the massage, these values altered to 10.1±1.0cm · s^{-1} and 8.55±0.9cm · s^{-1} for effleurage and petrissage respectively. The values were not significantly different from those of resting, indicating that manual massage does not have any significant effect on blood flow.

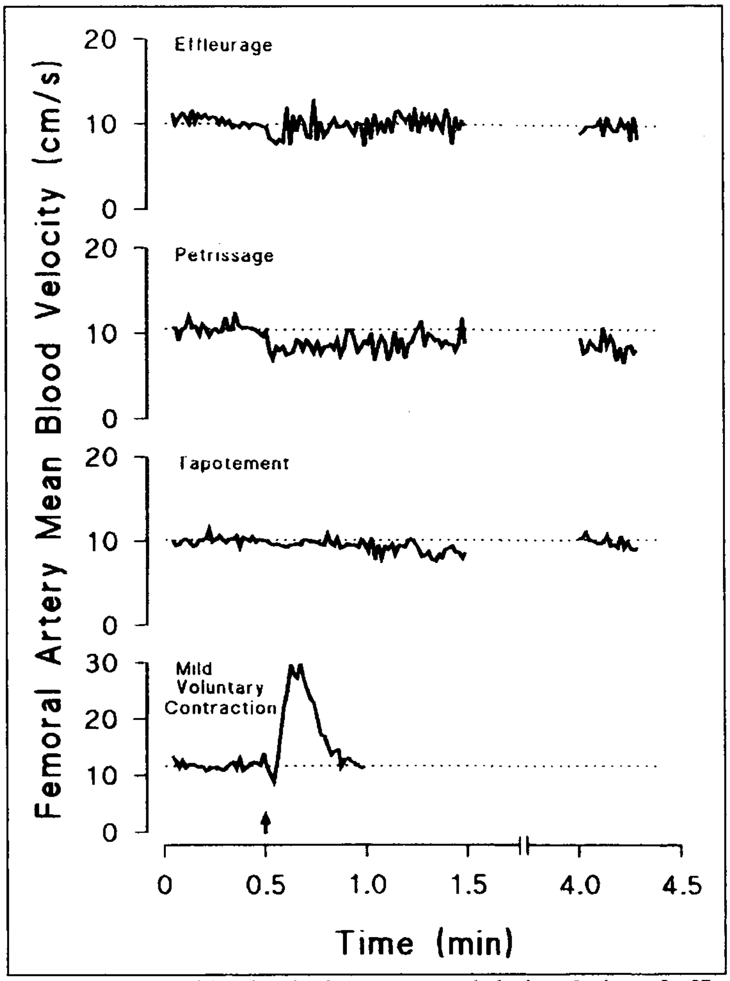


Figure 1.3 Femoral artery mean blood velocity at rest and during 5mins of effleurage, petrissage, tapotement forms of massage, and following brief voluntary quadriceps contraction. Arrow indicates onset of massage or exercise (Reproduced from Shoemaker, Tiidus & Mader, 1997).

In contrast, during light quadriceps contractions, mean blood velocity in the femoral artery increased from 9.73±0.7cm · s^{-1} at rest up to 28.1±3.1cm · s^{-1}. This change was significantly different from baseline and massage. Shoemaker, Tiidus & Mader (1997) concluded that although massage may cause a disturbance in systemic venous blood and lymph flow, the data does not support the theory that massage significantly elevates blood flow above resting values.

Hinds *et al.*, (2004) reported that post-exercise massage of the leg following 3 x 2min bouts of concentric quadriceps exercise, did not cause an increase in total limb blood volume or flow (by measuring femoral artery blood flow), but did increase blood flow to the skin and increased muscle temperature. This increase in blood flow is characterised by redness of the skin, and by an increase in surface temperature, mainly caused by friction of the therapist's hands on the subject's skin.

Therefore, research evidence now suggests that manual massage may not be as effective at increasing blood flow as previously thought.

1.8.2 The effect of vibratory massage on limb blood flow

Limb and whole body vibration increases limb blood flow (muscle and skin) and skin temperature (Oliveri, Lynn & Hong, 1989). This increased skin temperature has also been associated with moderate itching and erythema, particularly in the calf, ankle and foot (Rittweger, Beller & Felsenberg, 2000).

Stewart, Karman, Montgomery & McLeod (2004) investigated the effect of plantar vibration on leg blood flow, and reported that following a whole leg vibration at a frequency of 45Hz, there was increase in blood flow in the calf (measured at the midpoint between the ankle and upper calf) and pelvic (mid point between knee and iliac crest) regions by 30% and 26% respectively. They concluded that the results imply that vibration significantly enhances peripheral blood flow and venous drainage. Similarly, Lohman, Petrofsky, Maloney-Hinds, Betts-Shwab & Thorpe (2007) investigated the effect of whole body vibration on blood flow of the legs, by measuring the skin flow of the right distal leg with a Doppler imager. They concluded that 30-50Hz of body vibration caused a significant increase in limb blood flow from 112±37.01 to 277.53±179.74 flux units.

Kerschan-Schnidl *et al.*, (2001) investigated the effect of low frequency whole body vibration on peripheral circulation. The 20 subjects in the study were vibrated for 9mins at a frequency of 26Hz. The results indicated that full body vibration increased mean blood flow in the popliteal artery from 6.5 to 13cm · sec^{-1}; in addition, peripheral resistance was significantly reduced.

1.9 The effect of massage on blood lactate concentration following exercise

1.9.1 Lactate production following intense exercise

The demands during intense short term anaerobic exercise leads to insufficient oxygen supply to meet the energetic demands of the active muscles, which will result in the degradation of glycogen to glucose through glycogenolysis, and the production of lactate and H^+ within the skeletal muscle cells, which reduces pH (McArdle, Katch & Katch, 2007). This increase in H+ and subsequent decrease in pH, along with phosphate ion accumulation leads to a disruption of muscle contraction and thus causes fatigue (Allen & Westerblad, 2001; Westerblad, Allen & Lännergren, 2004, Pathare *et al.*, 2005).

Whilst the majority of lactate accumulated during the short term exercise bout is removed by direct oxidation within the muscle cells (Brroks, 2000), the lactate that is not oxidised diffuses from the exercised muscle into the capillaries, and it is transported via the blood to the liver where it is converted to glucose through gluconeogensis via the Cori cycle (McKardle, Katch & Katch, 2007). In turn, this glucose can be either used or stored by the skeletal muscles.

The increase in blood lactate reflects the alteration in balance between production and oxidation within the muscle, and it is known that any increase in muscle lactate will lead to a concomitant increase in blood lactate (Donovan & Brooks, 1983; Gladden, 2000; Brooks, 2000; and Gladden, 2004).

In addition, following a bout of short term intense exercise research by Hussain, Smith, Medbak, Wood & Whipp (1996); and Vincent *et al.*, (2004) has reported a decrease in pH, bicarbonate & potassium and an increase in lactate, H^+, adenosine, sodium, norepinephrine and plasma epinephrine, which have an effect in the alteration of blood pressure, by lowering diastolic pressure due to sustained peripheral vasodilatation in the lower limbs. This lowering of diastolic pressure below 50mmHg (Hussain, Smith, Medbak, Wood & Whipp, 1996) can also have an effect on cerebral blood flow, causing individuals to feel nauseous, light headed and lethargic.

It is proposed that one of the main advantages of massage administration post exercise is its ability to overcome fatigue and promote recovery. It has been speculated that massage can enhance the oxidation of lactate and promote recovery from intense exercise, through increased blood flow to the muscle. Whilst it is beyond the focus of this study to investigate the effect of massage on muscle energetics *per se*, as blood lactate concentration is a reliable biochemical marker to monitor recovery, it was used in the present study (von Duvillard, 2001).

1.9.2 Preliminary research into the effect of massage on blood lactate concentration decrease

Previous data regarding the effect of massage on blood lactate concentration is contradictory. Bale & James (1993) and Jones & Cotterell (1999) show a decrease in concentration, but contradict several studies that together suggest very little difference between rest and massage at decreasing BLa concentration (Hemmings *et al.*, 2000 and Robertson *et al.*, 2004) (Table 1.5).

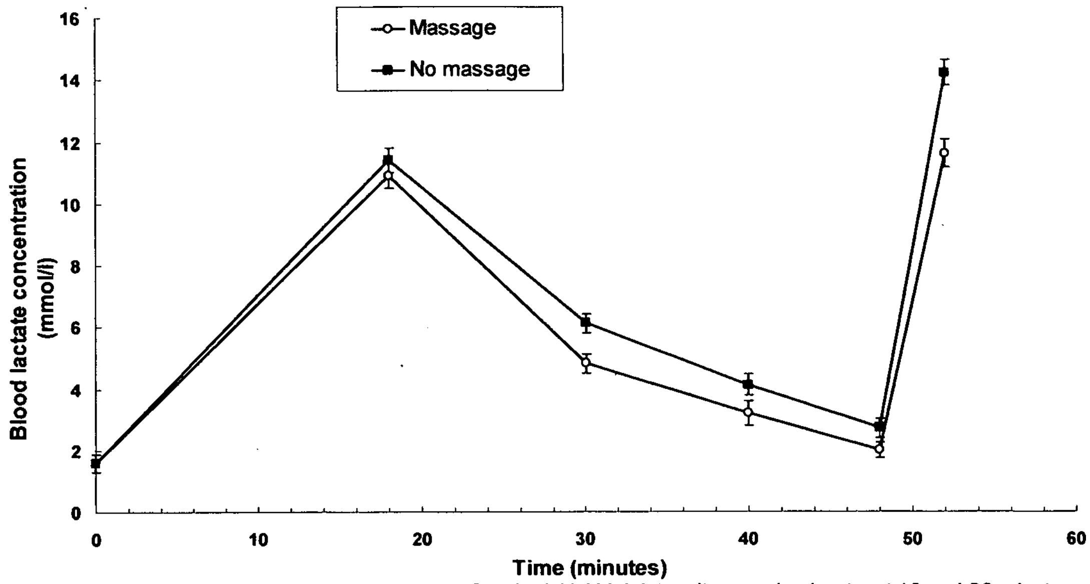
Table 1.5 Comparison of studies using manual massage as a mode of recovery to decrease blood lactate concentration.

Author	Exercise type	Massage duration	Area treated	Increased (↑) or no effect (↔) on clearance
Jones & Cotterell (1999)	30sec Wingate test	30mins	Whole Leg	↑
Dolgener & Marien (1993)	30sec Wingate test	20mins	Whole Leg (20mins)	↔
Gupta, Goswami, Sadhukhan & Mather (1996)	1min cycle ergometry at 150%VO_{2max} until (15secs rest) until exhaustion	10mins	Arms (5mins) and Legs (5mins)	↔
Martin, Zoeller, Robertson & Lephart (1998)	3 Wingate tests (5mins rest between)	10mins	Legs (5mins each)	↔
Robertson, Watt & Galloway (2004)	5km cycling time trial	20mins	Legs (10mins each)	↔
Monedero & Donne (2000)	5km cycling time trial	15mins	Legs (7.5mins each)	↑
Hemmings, Smith, Graydon & Dyson (2000)	5 x 2 min simulated boxing bout (1 min recovery between rounds)	20mins	Arms (10mins) and Leg (10mins)	↔
Ogai, Yamane, Matsumoto & Kosaka (2008)	8 x 5secs repeated at 20sec intervals (0.75g kg^{-1}). Exercise repeated after 20mins supine rest	10mins	Calf (10mins)	↔

A pilot investigation was conducted (and is presented in Appendix 2) and adopted the 30sec Wingate Anaerobic Test (WAnT) as one form of exercise which elicits a large increase in blood lactate and heart rate. Following the supramaximal test, the 30min recovery period required subjects to either rest (R), exercise lightly on a cycle ergometer at 60%HR_{max} (CE), or receive a manual leg massage (MM). The results of both investigations confirmed that light exercise decreases blood lactate concentration more rapidly than Rest during short term recovery. In the pilot investigation, at 30mins post WAnT BLa concentration for CE (3.1±0.5mmol · l^{-1}) was significantly lower than R (7.2±0.6mmol · l^{-1}). Manual leg massage was significantly more effective than Rest alone, lowering BLa to 5.9±0.9mmol · l^{-1}. Manual leg massage also decreased heart rate, and despite not reaching significance, it was lower than Rest suggesting a possible short-term parasympathetic effect. Conversely, Drust *et al.*, (2003) reported an increase in heart rate during massage, when compared to Rest, following a bout of supra maximal exercise. The preliminary investigation by Jones & Cotterell (1999) also measured delayed onset of muscle soreness, with a subjective scale, following each recovery method. The results showed that the 30sec exercise bout was too short to cause sufficient measurable long term muscle damage. Therefore, it was decided that measures of muscle damage, pain scale and creatine kinase, would be omitted when investigating the effect of massage on short term recovery from anaerobic exercise during this study.

1.9.3 The effect of combining light exercise with massage on blood lactate concentration following intense exercise

As light exercise decreases blood lactate concentration rapidly, but massage has a significantly greater effect psychologically (Hemming, Smith, Graydon, & Dyson, 2000; and Hemmings, 2000b), a regime of combining the two is hypothesised to be even more effective than the individual modes alone. Therefore, during the present study the effect of a combined recovery regime (active + leg massage) on recovery following intense exercise would be investigated. Monedero & Donne (2000) report that a combined recovery regime (3.75mins cycling exercise @ 50%VO_{2max} + 7.5mins leg massage) was the most efficient at promoting recovery from intense exercise, and maximising subsequent performance. Micklewright *et al.*, (2003) report an identical effect when combining low level cycling exercise with manual leg massage. Conversely, Robertson, Watt & Galloway (2004) report no significant difference between massage and Rest, when combined with light exercise, following intense short-term exercise. Despite their definitive conclusion, blood lactate concentration for massage appeared to be visibly lower throughout the whole recovery phase (Figure 1.4). This may reflect an increase in blood flow by the massage therapy, that in turn would increase oxygen delivery to and uptake by the muscle, and therefore reduce the dependency on anaerobic metabolism. This may therefore decrease blood lactate concentration.



Mean (SEM) blood lactate concentration at rest, after the initial high intensity exercise bouts, at 10 and 20 minutes of intervention, immediately before the Wingate test, and three minutes after the Wingate test. No significant difference was observed between trials at any time (Reproduced from Robertson, Watt & Galloway, 2004).

Figure 1.4 Blood lactate concentration after high intensity exercise bouts (data from Robertson, Watt & Galloway, 2004).

1.10 Is massage as a method of decreasing the indices of acute muscle damage following eccentric exercise to exhaustion (creatine kinase concentration, and muscle pain)?

1.10.1 The effect of massage on creatine kinase concentration following eccentric exercise to exhaustion

Creatine kinase (CK) is the principal enzyme in the reversible ADP↔ATP transformation. This muscle specific protein is a large molecule and therefore cannot enter the circulatory system directly (Voet & Voet, 1995). Instead, it enters the interstitial fluid, and then the systemic circulation via the lymphatic system (Hortobágyi & Deneham, 1989). An increased concentration of CK within the blood is indirectly indicative of muscle damage; however, the amount of CK present is no indication of the magnitude of damage as there is large inter-subject variability (Friden & Lieber, 2001 and Chen, 2006).

It has been hypothesised that manual or vibratory massage can prevent the CK release following EE, or decrease the values more rapidly once they have peaked.

Smith *et al.*, (1994) reported that a vigorous sports massage 2hrs following unaccustomed eccentric exercise reduced serum creatine kinase levels and neutrophil count at 8hrs, 24hrs, 48hrs, 72hrs, 96hrs and 120hrs, compared with the control resting group (Figure 1.5). Rodenburg, Steenbeek, Schiereck & Bärr (1994) also reported a reduction in CK when massage was administered immediately after 30mins of eccentric forearm flexion. However, they concluded that manual massage significantly reduced CK concentration following eccentric exercise, despite not affecting maximal force regain and range of movement of the elbow.

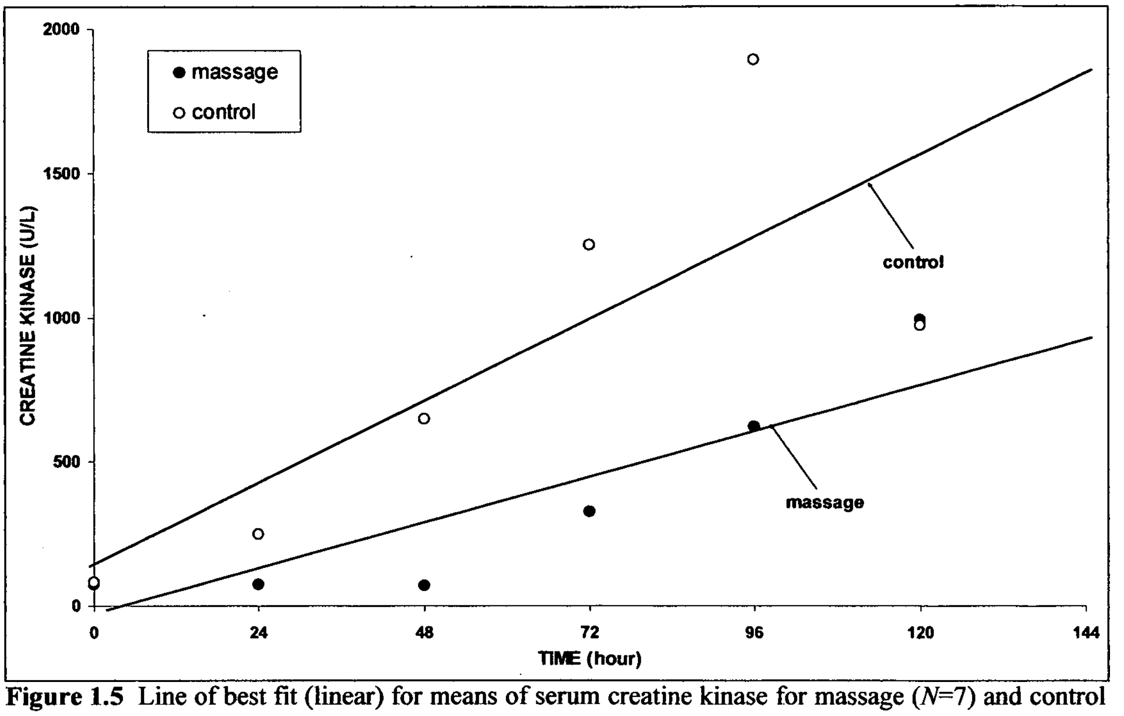


Figure 1.5 Line of best fit (linear) for means of serum creatine kinase for massage (*N*=7) and control (*N*=7) subjects (Data from Smith *et al.*, 1994)

Apart from the studies by Smith *et al.*, (1994) and Rodenburg, Steenbeek, Schiereck & Bärr (1994), there are very few studies which report a positive effect of massage on CK. Weber, Servedio & Woodall (1994) concluded that an 8min massage performed 0hrs and 24hrs after eccentric exercise had no significant effect at reducing CK when compared to microcurrent electrical stimulation, arm ergometery or Rest. Tiidus & Shoemaker (1995) also reported that massage had little effect on CK.

1.10.2 The effect of massage on the pain associated with acute muscle damage following eccentric exercise to exhaustion

The pain which occurs following eccentric exercise commonly peaks at 48hrs, and can range from being slightly uncomfortable to debilitating, and subsides over the course of a few days. The pain is most apparent when palpating or moving the affected area, and is normally most prevalent at the myotendinous junction (Smith *et al.*, 1994). The pain is thought to be a result of microscopic tearing of the muscle tissue, or damage to its contractile components; with the amount of tearing (and soreness) depending on the duration and intensity of the exercise bout.

The tissue damage following an eccentric exercise bout would cause pain through activation of afferent A-delta and C fibres nociceptors within the tendon and muscle of the arm (McHugh & McHugh, 2000). This tissue injury would also release pain mediators such as bradykinin, histamine, nitric oxide, prostoglandins and substance P (Gohar, 2005), which lower the firing threshold of the nociceptors and thus sensitise them further to any change in chemical or mechanical stimulus (Godfrey, 2005a).

The acute pain experienced following an eccentric exercise bout is due to the activation of the rapidly conducting A-delta fibres which transmit distinct sharp and localised pain, and the delayed unpleasant or unbearable pain is due to slow conducting C-fibres (Latham, 1985). The pain action potentials transmitted via the A-delta and C fibres synapse with the first interneuron, entering the posterior and anterior roots of the dorsal horn (Cross, 1994) and connect to second order neurons, which transmit signals to the third order neurons within the thalamus and reticular formation (Melzack & Wall, 1965; and Godfrey, 2005b).

Massage has been widely used in an attempt to ameliorate the painful effects, but with varied results. Tiidus & Shoemaker (1995), using an intense bout of eccentric quadriceps work with both legs, stated that the pain sensation was lower at 48hrs - 96hrs in the massage group (Figure 1.6), although muscle strength was not significantly different from the control group during the same time period. Smith *et al.*, (1994) report that a vigorous sports massage 2hrs following unaccustomed eccentric exercise reduced the sensation of DOMS. Furthermore, Farr, Nottle, Nosaka & Sacco (2002) report positive effects. Conversely, a more recent study by

Jönhagen, Ackermann, Eriksson, Saartok & Renström (2004) reported that following 300 maximal eccentric contractions of the quadriceps, muscle strength and pain were not positively affected by manual massage.

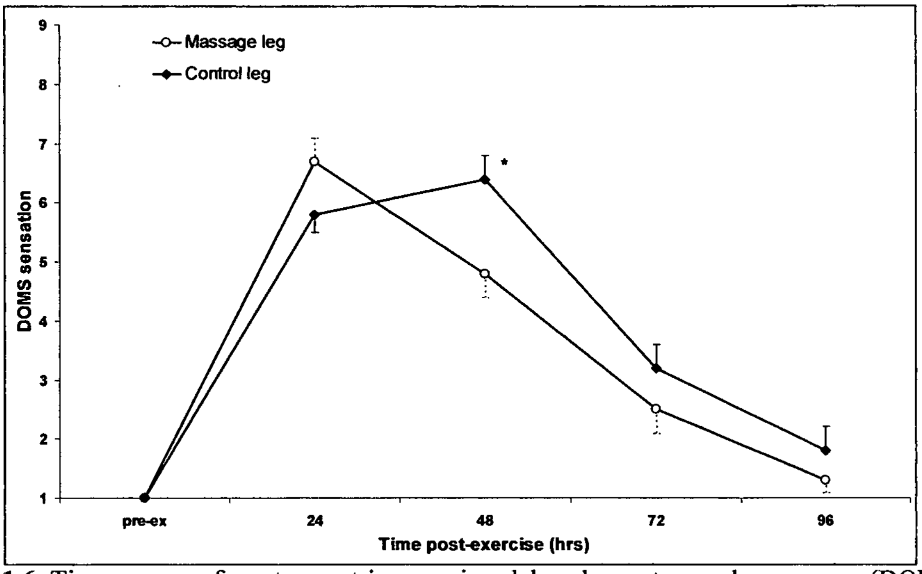


Figure 1.6 Time-course of post-eccentric exercise delayed onset muscle soreness (DOMS) for massage and control legs *Control *vs* Massage $p<0.05$ (Data from Tiddus & Shoemaker, 1995).

Due to its purported analgesic and aesthetic effects, vibratory massage has been used previously to ameliorate the effects of chronic pain (Gammon & Starr, 1941).. However, despite being recognised as an analgesic method of pain relief, little research has been completed to confirm its effectiveness (Smith, Comite, Balasubramanian, Carver & Liu, 2004). The question arises as to whether vibratory massage has a similar effect to manual massage in relieving pain after eccentric exercise.

It appears from the literature that vibratory massage has the greatest effect when applied at 40-100Hz, near or distal to the site of pain (Ottoson, Ekblom & Hasson, 1981; Sherer, Clelland, O'Sullivan, Doleys & Canan, 1986; Lundburg, 1986; and Cardinal & Wakeling, 2005); and the analgesia caused by vibration can last between 25mins up to two days, and even permanently depending on the amplitude and placement of the stimulus (Ottoson, Ekblom & Hasson, 1981). Despite these positive suggestions of pain relief, Lundeberg, Nordemar & Ottoson (1984) state that chronic pain will respond more favourably than acute pain to vibratory stimulus.

Perception of pain is a subjective measure and can have wide inter-subject variations, and therefore this may be a poor measure of muscle injury. This is because pain is not merely a one dimensional sensation, but a multitude of stimuli made up of a subject's level of stress, mood, pain tolerance and recovery expectations (Cleak & Eston, 1992; and Zainuddin, Newton, Sacco & Nosaka, 2005). However, Warren, Lowe & Armstrong (1999) suggest that this type of numerical scale with verbal anchors is sensitive enough to evaluate changes in pain, and subjects will be able to delineate between the different ratings. In a review of 52 human studies, Warren, Lowe & Armstrong (1999) reported that 63% used a numerical scale with verbal anchors as a subjective scale of soreness, and each successfully measured changes in pain. Therefore, it follows that the scale used in the present investigation is a valid tool for assessing the intensity of pain.

1.11 Massage as a method to promote acute muscle damage healing (reduction in limb swelling and restoration in muscle strength

1.11.1 Limb swelling and oedema following acute muscle damage

The inevitable swelling which occurs following a bout of eccentric exercise has two distinct phases; for the first three days, the muscle becomes enlarged and is firm to the touch. The second phase, which can last for more than 10 days causes the area to feel soft on palpation due to fluid within subcutaneous tissue (Chleboun, Howell, Conatser & Giesey, 1998). This swelling occurs when the accumulation fluid exceeds the capability of lymphatic drainage from the site (Nosaka & Clarkson, 1996a). It had been that intracellular oedema is a result of electrolyte redistribution across the cell membrane; and extracellular oedema is as a result of protein redistribution across capillary membranes (Friden, Sfakianos, Hargen & Akeson, 1988; and Chleboun, Howell, Conatser & Giesey, 1998).

Despite following the same trend as perceived pain and muscle strength, it is apparent from the literature that swelling plays little part in the cause of this pain, but does cause the stiffness associated with eccentric exercise (EE) (Proske & Morgan, 2001; and Howell, Chleboun & Conatser, 1993). Therefore, it would appear that clearance of oedema would not result in a lower level of perceived pain.

Swelling can persist for 10 days following an EE bout, and is at its highest 48-96hrs post exercise (Figure 1.7) (Chelboun, Howell, Conatser & Giesey, 1998; and Zainuddin, Newton & Nosaka, 2005). A straightforward and frequently used method to assess the magnitude of the limb swelling is to measure limb circumference. This can be done with a tape measure above and below the affected joint; in the case of this study (Investigation 5) it will be the elbow. It has long been known that manual massage has a positive effect at clearing oedema from affected limbs (Albury, 1934a,b), and by applying light force to the limb which promotes increased lymphatic flow (McNeely *et al.*, 2004).

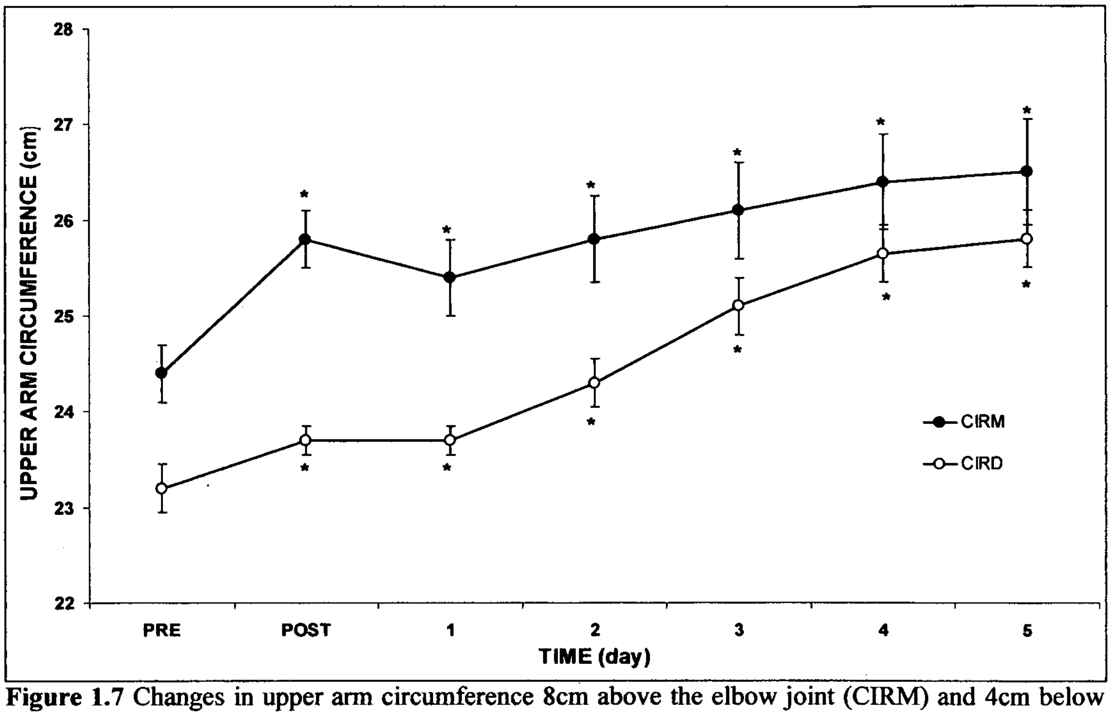


Figure 1.7 Changes in upper arm circumference 8cm above the elbow joint (CIRM) and 4cm below the elbow joint (CIRD) following 24 maximal eccentric biceps contractions (* $p<0.05$) (Data from Nosaka & Clarkson, 1996).

As lymphatic flow is not aided by circulatory pressure, only by valves similar to those seen within veins, gravity has a negative effect, especially in the lower limbs (Rowett, 1988 and Marieb, 2006). The demands on the lymphatic system are greatest when there is an increase in interstitial fluid volume, which is one of the consequences of acute muscle damage (Cash, 1996). The lymph vessels run parallel to the veins in the systemic system; and it has been proposed that centripetal effleurage massage strokes will stimulate transient flow (Pemberton, 1932 and Albury, 1934b). Despite there being very little recent scientific evidence substantiating the effects of massage on lymph flow, it is plausible that there will be a decrease in limb circumference measurement of an oedematous joint (e.g. elbow) post treatment.

Hart, Swanik & Tierney (2005) massaged subjects at 24, 48 and 72hrs post EE of the hamstring in nineteen subjects. They concluded that massage cleared oedema from the affected area, but this was only temporary, and oedema returned soon after the cessation of massage therapy. In comparison, Zainuddin, Newton, Sacco & Nosaka (2005) administered a 10min massage to the arm 3hrs after 60 maximal voluntary eccentric contractions of the elbow. They observed that, when compared to Rest, massage did indeed reduce swelling throughout the 14 day follow up. By 72hrs, the limb girth was 2.5±1.2mm above baseline for massage, compared to 7.8±1.4mm for Rest.

1.11.2 The effect of massage on muscular strength recovery following acute muscle damage

Loss of muscular strength immediately following eccentric exercise, and for many days after, is a well established and frequently reported consequence eccentric exercise (Golden & Dudley, 1992), and can be attributed in part to the muscle pain suffered by subjects (Farr, Nottle, Nosaka & Sacco, 2002). Strength has been shown to diminish 30-40% immediately following a bout of EE (Tiidus & Shoemaker, 1995; Hilbert, Sforzo & Swensen, 2003, and Jönhagen, Ackermann, Eriksson, Saartok & Renström, 2004), and recovers slowly during the subsequent days, depending on the intensity and duration of EE (Figure 1.8) (Zainuddin, Newton, Sacco & Nosaka, 2005).

Massage has been shown to have a mixed effect on strength regain, with the majority of research showing little effect; however Rodenburg, Steenbeek, Schiereck & Bärr (1994) showed that it had a significantly positive effect compared to Rest following 30mins of eccentric exercise with the forearm flexors.

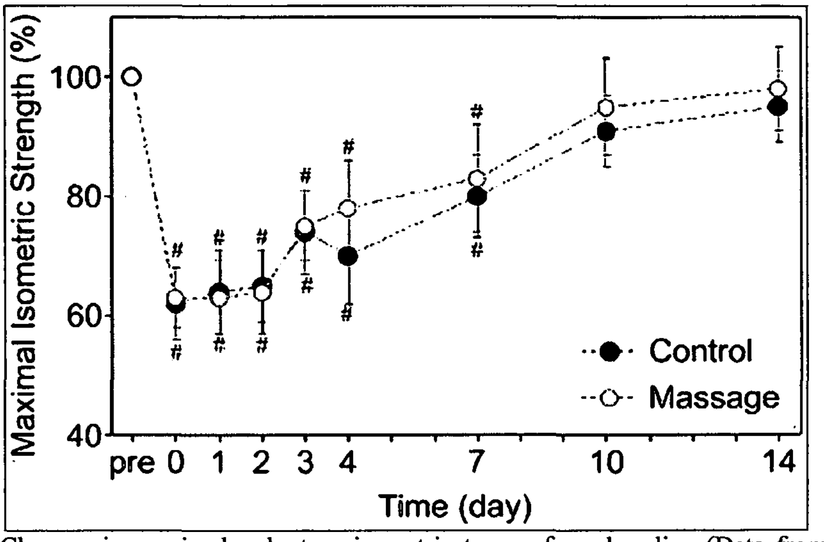


Figure 1.8 Changes in maximal voluntary isometric torque from baseline (Data from Zainuddin, Newton, Sacco & Nosaka, 2005).

1.12 The psychological effects of massage

The majority of the research currently available concurs that massage has a beneficial psychological response, by enhancing feeling and mood (Hernandez-Reif, Field & Hart, 1999), decreasing stress (Rexilius, Mundt, Erickson-Megel & Agrawal, 2002), decreasing arousal (Longworth, 1982), decreasing depression and anxiety (Moyer, Rounds & Hannum, 2004), and promoting a feeling of relaxation (Longworth, 1982; Boone & Cooper, 1995; Field *et al.*, 1996; Leivadi *et al.*, 1999; Zeitlin, Keller, Shiflett, Schleifer & Bartlett, 2000; Aourell, Skoog & Carleson, 2003, Delaney, Leong, Watkins & Brodie, 2002; and Diego, Field, Sanders & Hernandez-Reif, 2004). Furthermore, Hemmings *at al.*, (2000) and Hemmings (2000a & 2000b) report that massage is also effective at improving psychological wellbeing and perceived recovery following exercise, irrespective of any beneficial physiological response. A more detailed review of the literature and possible mechanism by which massage enhances psychological perception of feeling is presented in Chapter 3

1.13 Comparison between the manual and vibratory massage methods used in this study

The use of vibratory massage is becoming more widespread in the UK, despite being a therapeutic method with very little empirical research to substantiate claims made by manufacturers. In 2000, it was estimated that the sale of vibratory massagers had reached £2.5million (McDonagh, Wilson, Haslam & Weightman, 2005), with this increasing year by year, and predicted to be £4million in 2008 (MINTEL, 2001 &

2007). For the purposes of this study, it was decided that the G5® vibratory massage machine be used as a comparator to manual massage, as the G5® machine includes attachments which closely simulate manual massage techniques. The manufacturers of the G5®, Physiothérapie Générale France, based is Casteljaloux (France) and General Physiotherapy, based in Earth City (Missouri, USA), produce 12 different vibratory massage machines, and 20 applicators. Currently there have been over 100,000 machines sold worldwide (G5® Europe website, 2008). The manufacturers claim that the G5® does not aim to replace manual massage, but could either be used as an alternative, or used in conjunction with manual massage. Furthermore, they claim that the apparatus will have a similar physiological and psychological effect to that of manual massage.

The rate of vibratory massage can be altered, similar to the change in rate which occurs during manual massage; however, there are two main differences between manual and mechanical vibratory massage. With manual massage, the depth of stroke is altered to suit each individual subject. Superficial effleurage is light pressure, used as an introductory touch; and deep effleurage, which requires more pressure by the hand on the treated area. The manufacturers of the G5® advise that the 1.4kg head is placed on the skin and moved from distal to proximal without any additional downward forces by the therapist. Therefore, the pressure applied will not differ irrespective of any change in applicator or frequency. The second main difference, and perhaps the most important, is the touch interaction between the therapist and subject. Touch has been shown to decrease anxiety, heart rate and mean blood pressure, thus indicating a parasympathetic effect (Wendler, 2003 and McCaffrey & Taylor, 2005). During the present study, these differences may affect the physiological, as well as psychological variables measured.

Field (1998) recommended that any future research which attempts to elucidate the physiological and psychological effects of massage should compare both manual and vibratory massage methods in order to gain an accurate comparison. Therefore, in order to fully investigate and elucidate the physiological and psychological effects of massage administration at rest, and during recovery from exercise in this study, manual massage will be directly compared to vibratory massage.

In light of the previous studies outlined here, there are still unresolved issues relating to the proposed benefits of massage in general, and/or mode of massage (manual or vibratory). These issues are summarised below:-

1.13.1 Cardiac autonomic function

The effects of back, shoulder and neck massage at enhancing relaxation by decreasing sympathetic drive are apparent (Barr & Taslitz, 1970; Delaney, Leong, Watkins & Brodie, 2002; McNamara, Burnham, Smith & Carroll, 2003; and Aourell, Skoog & Carlson, 2005). However, there is no evidence in the literature detailing the effect of manual or vibratory leg massage on cardiac autonomic activity either at rest, or during recovery from exercise.

1.13.2 Blood pressure Rate pressure product response

Although there is consensus regarding the effect of manual massage on systolic blood pressure, there is no data regarding the effect of vibratory massage. Furthermore, there is no data presented regarding the rate pressure product index and how a decrease following massage may correlate with increased parasympathetic and decreased sympathetic drive.

1.13.3 Metabolic rate (oxygen uptake and carbon dioxide production)

It is apparent from the literature that there is no consensus of opinion regarding the effect of manual massage, and very little research investigating the effect of vibratory massage on metabolic rate.

1.13.4 Respiration (pulmonary ventilation, respiratory rate and tidal volume)

Previous studies have strongly suggested that massage decreases respiratory rate. However, it is evident that the effects on pulmonary ventilation remain to be elucidated. As such, it was of interest in the present study to clarify the effects of massage on respiratory rate, tidal volume and pulmonary ventilation.

1.13.5 Limb blood flow

It is apparent that there is a body of work investigating the effect of manual massage on blood flow at rest; however, there is lack of research data investigating the comparison to vibratory massage, or investigation into the effects on blood flow post aerobic exercise.

1.13.6 Blood lactate concentration

There is a lack of consensus regarding the effect of massage on blood lactate clearance post exercise. Therefore, this present study's aim was to investigate this, and attempt to test whether the use of massage is an effective as a short term recovery method from intense exercise. Secondly, is the effect of mechanical vibratory massage on lactate clearance similar to that of manual massage following exercise?

1.13.7 Recovery from acute muscle damage

It is evident that there is no consensus regarding the effect of manual massage, and paucity of research investigating the effect mechanical vibratory massage, on creatine kinase clearance following acute muscle damage. Furthermore, there is evidence from the literature that massage appears to clear oedema and decrease limb swelling following acute muscle damage compared to control Rest. However, there is paucity of research studying the effects of vibratory massage on this variable; therefore, this study was examined the effects of vibratory massage on CK and oedema clearance and limb swelling following acute muscle damage.

There appears that there is no consensus regarding the effect of either manual or vibratory massage on pain reduction following acute muscle damage. Therefore, the aim of this study was to investigate the effectiveness of the two massage modalities at reducing pain following acute muscle damage.

1.13.8 Psychological effects

There positive psychological effects of manual massage are evident. Therefore, the study aimed to elucidate whether vibratory massage had a similar effect psychological effects at rest and during recovery from exercise.

1.14 Study aims and research questions

This is the first collection of research investigations specifically aimed at a direct comparison between manual and vibratory massage following exercise, drawing conclusions regarding both the physiological and psychological effects of VM. The overall aim of this study was to gain a greater understanding of the physiological and psychological effects of massage (manual compared to vibratory) when administered at rest, or during recovery from exercise. In order to test the effects of massage on recovery from exercise comprehensively, three different types of exercise were chosen, namely aerobic, anaerobic and eccentric.

In order to elucidate the effect of massage, this study aims to answer the following research questions:-

1. What effect does massage have on cardiac autonomic activity, heart rate, blood pressure, and rate pressure product?
2. Does massage have an effect on respiration and metabolic rate?
3. Does massage increase leg skin temperature? Does this increase have an associated effect on body temperature (as measured by aural temperature)?
4. Does massage alter limb blood flow (measured using a plethysmograph)?
5. Does massage accelerate blood lactate concentration clearance during recovery following exercise? Can combining massage with light exercise during the initial stages of recovery have a greater effect on lactate clearance than massage alone?
6. Does massage have a positive psychological effect? Can the administration of massage immediately following exercise ameliorate any subsequent perceived pain? If so, what is the cause?
7. Is the physiological and psychological response of massage administered at rest similar to the response when massage is administered during recovery from exercise?
8. Is there any difference in the physiological and psychological response between manual and vibratory massage?

In order to answer these research questions, five investigations were divided into four themed results chapters; with each chapter having more detailed aims and hypotheses dealing with massage at rest (Investigation 1 & 2), following aerobic exercise (Investigation 3), following maximum anaerobic exercise (Investigation 4), and following eccentric exercise (Investigation 5).

1.15 Hypothesis

H_0 The administration of mechanical vibratory massage (VM) at rest and during recovery from aerobic, anaerobic and eccentric exercise will be equally as effective as manual massage on physiological and psychological variables.

H_1 The administration of mechanical vibratory massage (VM) at rest and during recovery from aerobic, anaerobic and eccentric exercise will have no beneficial physiological or psychological effect compared to manual massage.

CHAPTER 2

MASSAGE TECHNIQUES &
GENERAL MATERIALS AND METHODS

2.1 Manual and vibratory massage techniques used in this study

The techniques for manual and vibratory massage used during this present thesis are detailed below. The specific techniques used and duration of massage administration are detailed within each investigation.

2.2 Manual massage techniques

Callaghan (1993) states that massage techniques, administration and duration vary widely between therapists; however, the basic techniques used have remained unchanged for centuries. Individual massage strokes can be categorised in a number of different ways, and Table 2.1 details the different variations of massage stroke which were used in the present study.

Table 2.1 Classification of manual massage techniques

Stroke	Variation
Stroking / Effleurage	Superficial Deep
Petrissage (pressure)	Kneading Picking up Wringing Skin rolling

2.2.1 Stroking and Effleurage massage techniques: The terms stroking and effleurage are interchangeable, with the techniques being very similar in nature. Therefore, the generic term effleurage will be used for the remainder of this review.

Taken from the French *effleurer*, meaning to 'skim over' or 'stroke' (DeDomenico, 2007), effleurage is a rhythmic stroking movement performed with the entire palmar surface of the hand (Figure 2.1 & Table 2.2), passing distal to proximal, parallel along the axis of the underlying muscle tissue (Goats, 1994, and DeDomenico 2007). There are two different types of effleurage, namely superficial (Figure 2.2), and deep (Figure 2.3). Superficial effleurage is normally applied at the beginning and end of the treatment, and the smooth continuous slow strokes are applied with light pressure. This technique has several purposes, which include:-

- Introducing the subject to the massage, and putting the subject at ease
- Warming the tissues
- Stimulating peripheral nerves
- Palpating the tissues
- As a linking manoeuvre between other massage techniques

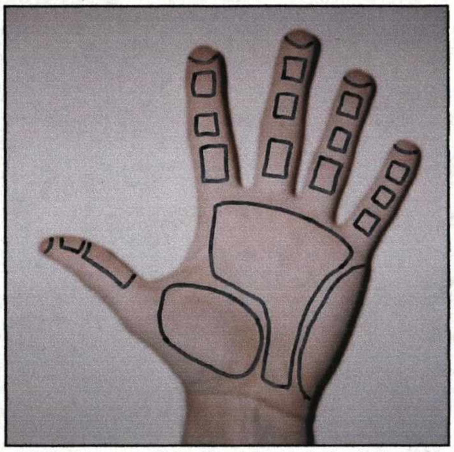


Figure 2.1 Areas of the hand used during a massage

Table 2.2 Areas of the hand that can be used to administer manual massage

- The whole palmar surface of either or both hands
- The ulna border of the hypothenar eminence
- One or more fingertips
- One or more finger pads
- Either or both thumbs

As the massage progresses, pressure is gradually increased from superficial touching to deeper strokes, affecting the subcutaneous layer and stimulating the fascia.

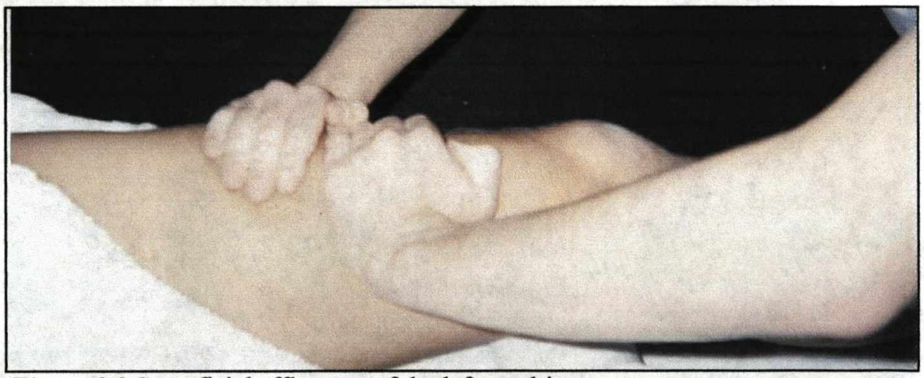


Figure 2.2 Superficial effleurage of the left quadriceps.

Figure 2.3 Deep effleurage of the right calf.

2.2.2 Petrissage massage technique: From the French petrir, 'to knead' (DeDomenico, 2007), petrissage is the generic term used for several classifications of massage strokes, four of which are listed in Table 2.1. The main purpose of this technique is to manipulate and lift tissue. When the tissue is lifted by one hand, the other is used to squeeze; with this process being repeated several times whilst moving up and down the area being treated. The techniques most applicable to the present study are kneading, picking up and wringing.

2.2.3 Kneading: Kneading is the movement of muscle and subcutaneous tissue, consisting of the slow circular compression of tissue against underlying bone (Norris, 1998 and DeDomenico, 2007). Along with the large areas such as the quadriceps which can be massaged with the palmar surface, smaller areas such as the calf (Figure 2.4) and biceps can be treated using the finger or thumb tips alone (Goats, 1994).

Figure 2.4 Kneading of the right calf.

2.2.4 Picking up: Of a similar nature to kneading, picking up involves the grasping and squeezing of one or more muscles with a circular motion (Norris, 1998). The technique is commonly used in smaller areas (e.g. triceps and tibialis anterior (Figure 2.5)) where kneading is not possible (DeDomenico, 2007).

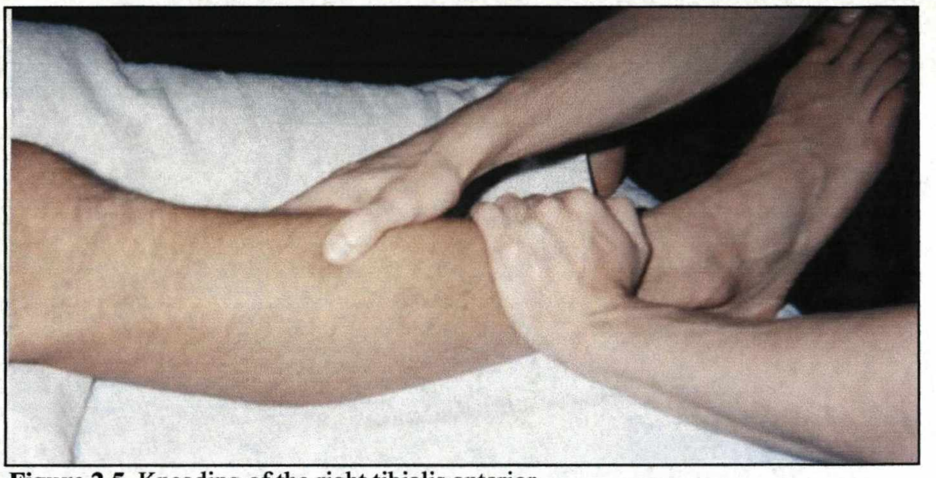


Figure 2.5 Kneading of the right tibialis anterior.

2.2.5 Wringing: As the name suggests, the technique involves the lifting and twisting of superficial tissue in opposite directions, mobilising muscle tissue and stimulating deeper circulation, thus promoting relaxation and pain relief (Ylinen & Cash, 1988) (Figure 2.6).

Figure 2.6 Wringing of the right hamstring.

During the six investigations in this study, for 10mins prior to the administration of the leg/arm massage, the therapist immersed both hands and a bottle of grapeseed oil in a heated water bath at 31°C. The temperature of the water was selected to replicate skin temperature.

2.3 Vibratory massage techniques

The mechanical vibratory massage machine used during the present investigation was the G5® 'Workout Masseur' machine (Figure 2.7). The machine features a continuously variable speed range of 10-60 cycles per second, with the integral motor driving a vibrating head (1.4kg), which oscillates in an anticlockwise direction, and deviates by 5mm from its central axis (Figure 2.8). The different applicators are attached to the vibrating head, with the different attachments simulating various manual massage techniques and strokes.

Figure 2.7 G5® 'Workout Masseur' vibratory massage machine

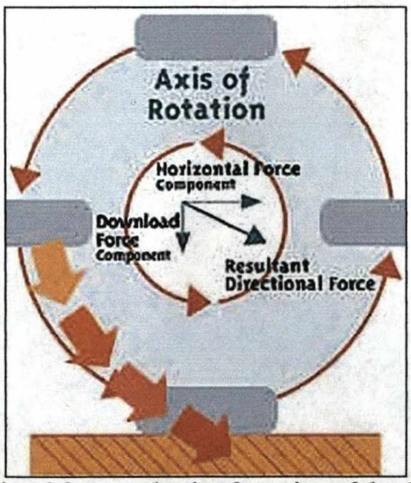


Figure 2.8 Directional force and axis of rotation of the G5® weighted head

The four attachments used during the present investigations were the U-shaped and rounded sponge adapters (Figure 2.9 & 2.10), which are designed to simulate effleurage; and the 4-ball and 2-ball adaptors were used to simulate petrissage (Figure 2.11 & 2.12).

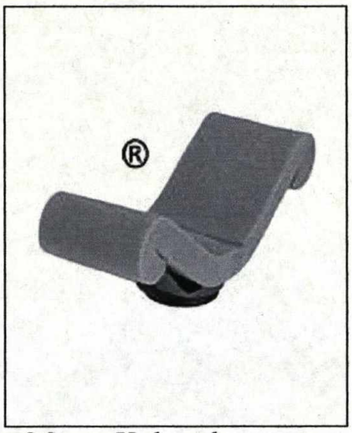


Figure 2.9 U-shaped sponge adaptor (applicator 230). Used on larger areas such as quadriceps and hamstrings to simulate effleurage

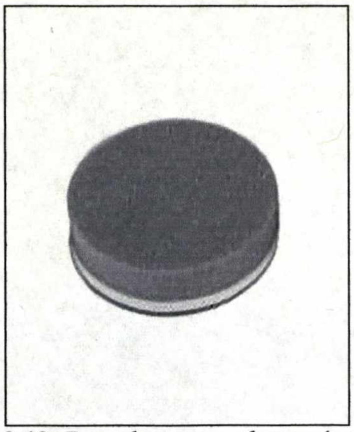


Figure 2.10 Round sponge adaptor (applicator 210). Used on smaller areas such as calf and triceps to simulate effleurage

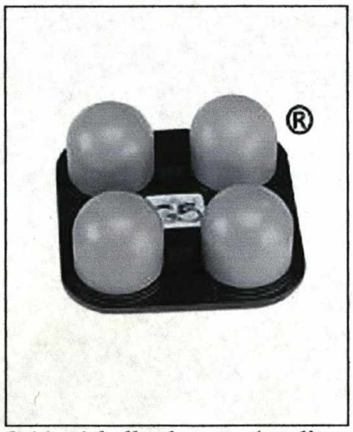


Figure 2.11 4 ball adaptor (applicator 216). Used on larger areas such as hamstrings to simulate petrissage

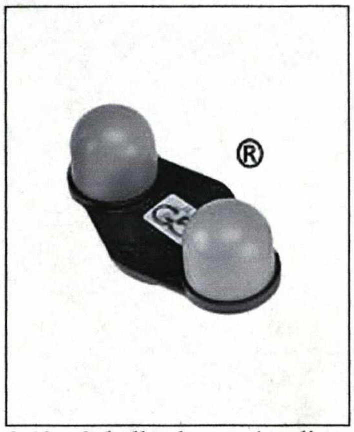


Figure 2.12 2 ball adaptor (applicator 223). Used on smaller areas such as biceps and anterior tibialis to simulate petrissage

For 10mins prior to the administration of the vibratory massage, the adaptors were heated in a water bath at 31°C. The temperature of the water was selected to replicate the skin temperature of the subjects.

2.4 Duration of massage administration in the present study

Presented in Table 2.3 is the rational for selecting the specific duration of massage during the present study.

Table 2.3 Investigation number, duration of massage, and rational for selecting the duration of massage during the present study.

Investigation	Duration of massage	Rational for selecting the duration of massage during the present investigations
1	30min whole leg massage at rest	30mins was deemed an appropriate duration for a whole leg massage, and is consistent with the recommendations detailed in Cash (1999), Boone & Cooper (1995), and DeDomenico (2007).
2	10min single leg calf massage at rest	The investigation attempted to validate the work of Bell (1964) and Wyper & McNiven (1976), by examining the effects of calf massage on limb blood flow. The duration of massage during the present investigation was consistent with the aforementioned studies.
3	20min single whole leg post aerobic exercise	It was expected that a 20min leg massage would be sufficient to promote short term recovery by reducing lactate, heart rate and blood pressure to baseline; and cause an alteration in skin blood flow, based on the work by Bale & James (1991), Drust *et al*,. (2003) and Hinds *et al*,. (2004).
4	45min continuous and combined whole leg massage post anaerobic exercise	The duration was extended compared to the preliminary study by Jones & Cotterrell (1999) and pilot study in Appendix ?.
5	8min whole arm massage post eccentric exercise	The time of administration is consistent with the recommendation for the duration of arm massage, detailed in Cash (1999) and DeDomenico (2007).

2.5 General materials and methods

Detailed below are the general materials and methods used in this study. Specific materials and methods, and the timeline of measurements are detailed within each investigation.

2.5.1 Heart Rate (all investigations)

Heart rate was monitored using a Polar 810*i* heart rate monitor (Polar Electro, Kempele, Finland). The transmitter belt was positioned immediately below the xiphoid and tightened so that a good connection was obtained, but not too tight so as to cause any discomfort.

2.5.2 Heart Rate Variability (Investigation 1, 2 & 3)

The Polar 810*i* heart rate monitor was used to collect R-R data, which was then analysed using the Polar Precision Performance software (Polar Electro, Kempele, Finland). Subjects lay in a supine position on a treatment couch and were requested to remain still and quiet throughout. R-R was measured for 5mins, which has been deemed the optimum time for short term R-R recordings (TaskForce, 1996; Delaney, Leong, Watkins & Brodie, 2002; and Bruce-Low, Cotterell & Jones, 2006). Respiration was not controlled and subjects were requested to minimise any conscious alterations in respiration. A preliminary study investigating the effect of controlled and spontaneous breathing on components of HRV is presented in Appendix 3. It demonstrates that there were no differences between the R-R interval tachograms or the frequency and time domain components of HRV when breathing was controlled or spontaneous.

Heart rate variability (HRV) was analysed in both time and frequency domains as defined by The TaskForce of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (TaskForce) (1996). It was calculated following the removal of any abnormal beats. The time domain measurements are presented as heart rate (bpm), square root of the mean of the sum of the squares of differences between adjacent R-R intervals (ms) (RMSSD) and number of pairs of adjacent NN intervals differing by more than 50ms (%) (pNN50). Frequency domain measurements are presented as normalised low (sympathetic) and high (parasympathetic) frequencies. Finally, to estimate sympatho-vagal balance, a ratio of LF:HF was calculated from absolute units (Dishman *et al.*, 2000).

2.5.3 Systolic and Diastolic blood Pressure (all investigations)

Blood pressure was recorded from the upper left arm using an Omron M5-1 digital sphygmomanometer (Omron Healthcare Europe BV, Hoofddorp, NL). The blood pressure cuff was placed on the arm 5mins before the first measurement; and the cuff remained deflated *in situ* between measures until the final reading.

2.5.4 Rate pressure product (all investigations)

Rate pressure product was calculated by multiplying heart rate and systolic blood pressure, which were measured instantaneously by the Omron M5-1 sphygmomanometer.

2.5.5 Metabolic rate and pulmonary ventilation (Investigation 1 & 4)

The Cosmed K4b2 gas analyser (Cosmed, Roma, Italy) was used to record breath-by-breath respiration in Investigation 1, 3, 4.

The analyser was calibrated in an identical manner prior to each testing session, firstly by using ambient air (20.93% O_2 and 0.03% CO_2), secondly by using calibration gas (15.01% O_2, 5.01% CO_2 and Nitrogen balance (±1%)) (βgas, BOC Medical, Ellesmere Port, UK), and thirdly by volume calibration using a 3-litre calibration syringe. To compensate for the time lag between expiration flow and the sampling of the expired air, a phase delay calibration was then completed; the average phase delay for O_2 was 424±11.7ms and 374±9.7ms for CO_2, which were within the manufacturer's acceptable range of 300 - 650ms. Furthermore, in order to standardise the analyser between tests and subjects, the atmospheric relative humidity, barometric pressure, ambient temperature, and subjects body mass were measured and entered into the Cosmed $K4b^2$ analyser unit.

The machine has been reported previously to be an accurate, valid and reliable analyser when used at rest and during exercise, and therefore deemed suitable for this study. The manufacturer's literature reports that the oxygen Gas Filtration Correlation analyser has a range of 7-24% and an accuracy of ±0.02%. In addition, the Non-dispersive Infra Red CO_2 analyser has a range of 0-8% and accuracy of ±0.01%. The reliability of the machine has been assessed by Duffield, Sawson, Pinnington & Wong, 2004). They reported that the analyser showed good repeatability for measurements of VO_2, VCO_2 and VE at rest and three different work rates; with all data points falling with the 95% confidence level. Furthermore, Hausswirth, Bigard & LeChevalier (1997), Eisenmann, Brisko, Shadrick & Walsh (2003), Duffield, Sawson, Pinnington & Wong (2004) and McNaughton, Sherman, Roberts & Bentley (2005) have all reported that the Cosmed K4b^2 analyser unit is a valid method for measuring VO_2, VCO_2 and VE when compared to the CPX Medical graphics, Cosmed Quark, Ametek and Morgan EX670 mass spectrometer analysers (respectively).

2.5.6 Aural and Leg Temperature (Investigation 1, 2, 3 & 4)

Leg skin temperature was monitored using an Ecolog TN4 datalogger (Elpro-Buchs AG, Buchs, Switzerland) and beaded probes. The temperature probes were placed on the skin, covered in a small piece of cotton wool in order to present the external temperature affecting the temperature readings, and attached by adhesive surgical tape and. Aural temperature was measured from the right ear using an infra red thermometer (Welch Allyn Braun Thermscan Pro 3000, Bodycare, UK). The probe was positioned within by ear canal in accordance with the manufacturer's guidelines; with the helix of the ear being pulled upwards and backwards as the probe was inserted into the ear canal. The probe remained *in situ* for 10secs prior to measurement.

2.5.7 Perception of Feeling (all investigations)

Subjects were required to register their perception of feeling on a 13-point biopolar good/bad feeling scale. Verbal anchors were provided at zero, and at all even positive and negative numbers (+6 Very Good; 0 Neutral; and -6 Very Bad). This scale was adapted from the scale developed by Kenney, Rejeski & Messier (1987) and Rejeski, Best, Griffith & Kennedy (1987). The word 'feeling' was defined to the subjects as a multifactoral sense of how their body was feeling, how they felt psychologically (stressed or relaxed etc.), and how they felt after exercise compared to how they felt before.

2.5.8 Plethysmography limb blood flow (Investigation 2 & 3)

A portable pneunoplethysmograph was used to estimate limb blood flow (PVL-50 Series 2, SkiMed, England) (Figure 2.13). Subjects lay in a supine position on a treatment couch with both legs positioned in accordance with the manufacturer's guidelines, with a soft leg support placed under the heels to stabilise the ankle and calf; and the leg was flexed at a 50° angle (Figure 2.14). A cuff (83cm x 11cm) was fitted around the maximum circumference of the calf, and another cuff (83cm x 13cm) was placed mid quadriceps. The subjects were requested to keep limb movement to a minimum throughout the measurement in order to minimise any movement artefact.

Figure 2.13 PVL-50 Series 2 portable plethysmograph

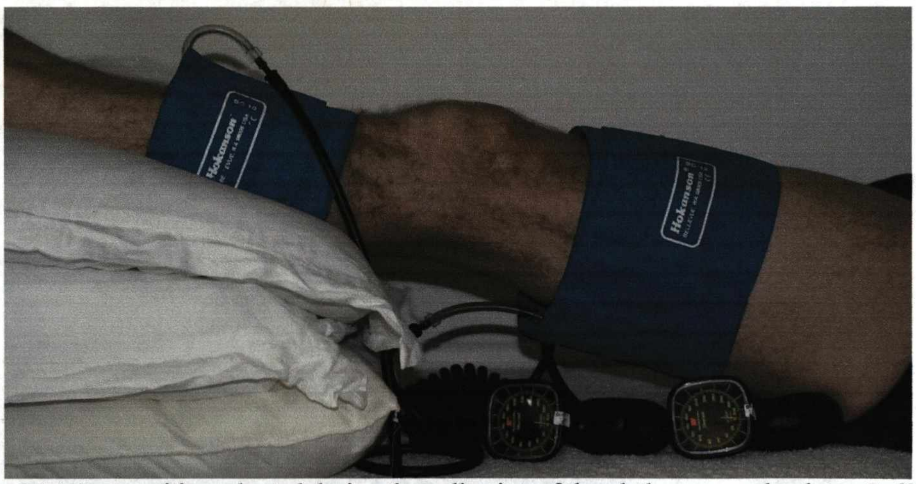
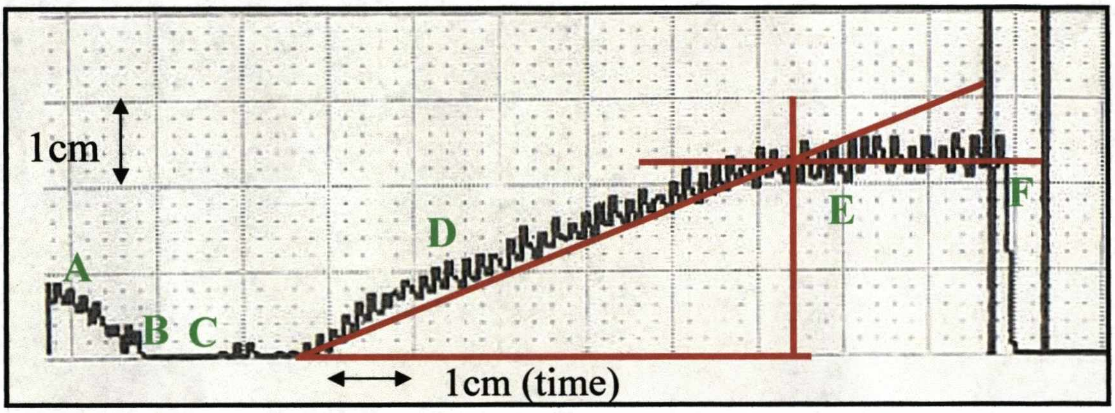


Figure 2.14 Leg position adopted during the collection of the plethysmography data. Cuffs were placed around the leg at the maximum circumference of the calf and thigh.

The calf cuff was inflated to 20mmHg, and the digital trace was allowed to stabilise and automatically zero (Figure 2.15). The thigh cuff was then inflated to 60mmHg which occluded venous blood flow within the limb. As arterial blood flow was unhindered by the cuffs, pressure within the limb increased until maximum venous capacitance was reached, which was signified by a visible plateau (Figure 2.16). At this point, the thigh cuff was deflated and venous blood flow was re-established.

In order to estimate limb blood flow, the average slope of the trace was drawn by eye. The slope of the volume trace was divided by the time taken to achieve maximum venous capacitance, thus calculating limb blood flow (Stegall, Martin & Rushmer, 1966; Vanhuyse & Raman, 1971; and Cable, 2001). The results of limb blood flow are reported in arbitrary units (*AU*).



A	Inflation of the calf cuff to 20mmHg
B	Stabilisation and automatic zero of trace
C	Inflation of the thigh cuff to 60mmHg
D	Increase in limb pressure
E	Plateau due to maximum venous capacitance
F	Thigh cuff pressure released and venous outflow

Figure 2.15 Venous volume displacement curve obtained from a healthy adult leg using a SkiMed PVL-50 plethysmograph, with annotated events.

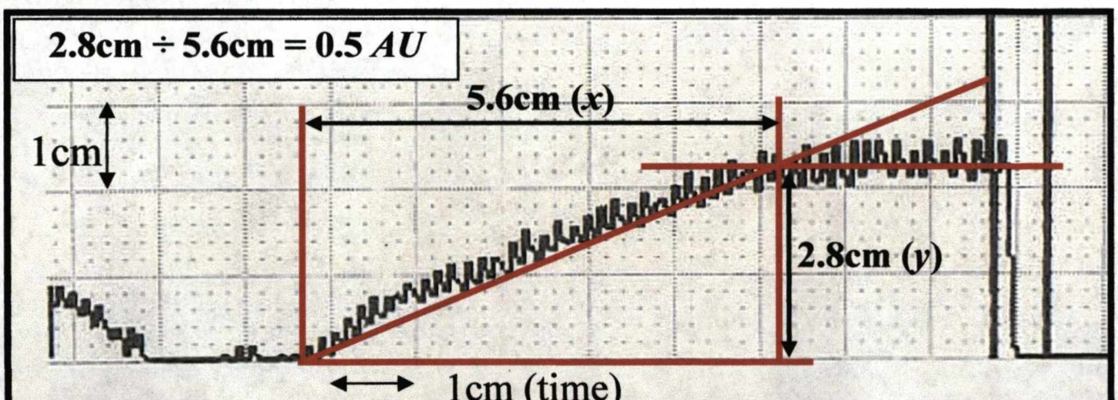


Figure 2.16 Calculation to estimate limb blood flow from a curve obtained from a healthy female adult leg using a SkiMed PVL-50 plethysmograph.

2.5.9 Blood lactate concentration (Investigation 3, 4 & 5)

Approximately 5μl of finger prick whole capillary blood from a warmed clean dry finger was analysed enzymatically for 60secs using a semi-automated Lactate Pro Test Meter (Arkray Inc., Kyoto, Japan).

2.5.10 Rating of Perceived Exertion (Investigation 3, 4 & 5)

Rating of perceived exertion (Borg, 1998) was measured on the 15 point scale with verbal anchors (0=No exertion at all; 20=Maximal exertion) in order to gauge their perceived intensity.

2.5.11 Maximal oxygen uptake (Investigation 3 & 4)

Maximal oxygen uptake was estimated via a continuous incremental cycling protocol on a calibrated Monark 818*E* weight loaded cycle ergometer (Monark Bodyguard, Varberg, Sweden) in accordance with the British Association of Sport and Exercise Science guidelines (Hale *et al.*, 1996). This involved a 5min warm up at 80watts (80rpm @ 1kg), followed by continual increments of 0.5kg every 1.5mins until exhaustion. Heart rate (HR) and rating of perceived exertion (RPE (Borg, 1998)) were monitored at the end of each workload. Subjects were verbally encouraged throughout the test. The criteria for the true determination of maximal effort and termination of the test were:-

- severe fatigue or exhaustion resulting in an inability to maintain exercise at a given work rate.
- a rating of perception of exertion of 19 or 20 on the Borg scale.
- a respiratory exchange ratio greater than 1.10;
- a plateau in the rise in heart-rate (Hale *et al.*, 1996)

2.6 Ethical approval

2.6.1 Medical/Health questionnaire

The medical//health questionnaire completed by the subjects participating in each investigation can be seen in Appendix 4.1. This was used to determine whether the subject was healthy and conformed to the inclusion criteria.

2.6.2 Informed consent forms

Ethical approval for the six investigations is detailed in the study were granted by either the Panel for Ethical Research (Biological Sciences) or by the Panel for Ethical Consideration (Centre for Exercise and Nutrition Science). The informed consent forms for each investigation can be seen in Appendix 4.2 to 4.6; with an additional consent form (Appendix 4.7) for subjects to register whether they have understood all the information presented to them, and whether they understand explicitly what is expected.

CHAPTER 3

The effect of whole leg massage administered at rest

(Investigation 1)

&

The effect of single leg calf massage administered at rest

(Investigation 2)

INTRODUCTION

Cuthbertson (1932) stated "Seize, squeeze with a quiet peculiar art every tired muscle, working and kneading....until within half an hour, whereas you were weary and worn out, you find yourself fresh, all soreness and weariness gone, and mind and body soothed to a healthful and refreshing sleep"

3.1 Overview

The three most plausible explanations of how massage achieves its results are that the repeated mechanical action of massage may increase limb blood flow, has a relaxation response by affecting the autonomic nervous system; and finally by altering metabolic rate.

This increase in blood flow could consequently increase oxygen delivery to the tissue, clear blood lactate, and hasten the return of normal internal muscle environment (Hinds *et al.*, 2004). Unfortunately, there is limited and contradictory evidence to support the hypothesis that massage improves blood flow to the muscles. The autonomic nervous system has also been proposed as one of the mechanisms by which therapeutic massage achieves its results, but until now, this effect has merely been inferred as massage has been reported previously to lower heart rate and blood pressure (Barr & Taslitz, 1970; and Longworth, 1982). Finally, despite the proposed benefits of massage, there remains little empirical research currently available to substantiate its effect on oxygen uptake and carbon dioxide production.

AIMS

3.2 Aims

3.2.1 The effect of whole leg massage administered at rest (Investigation 1)

The aim of this investigation was to elucidate the effect of manual and vibratory massage on cardiac autonomic activity, respiration, and metabolic rate; when administered at rest. In order to do this, the investigation compared the effect of a 30min manual leg massage (MM) and vibratory leg massage (VM); with passive Rest (R) acting as a control.

3.2.2 The effect of single leg calf massage administered at rest (Investigation 2)

The aim of this investigation was to further examine the beneficial effects of massage administered at rest. The duration of massage was reduced, in order to substantiate whether a shorter treatment time would initiate a similar response on cardiac autonomic activity to that seen in Investigation 1. Furthermore, the investigation attempted to validate and extend the work of Bell (1964) and Wyper & McNiven (1976), by elucidating the effects of calf massage on limb blood flow.

The investigation compared the effect of a 10min manual calf massage (MM) and vibratory calf massage (VM); with passive Rest (R) acting as a control. An additional period of 10mins rest was included at the end of the massage period. This was included to gauge whether any effects of massage would persist throughout the 10min period, or whether the relaxation effects are merely transient.

SPECIFIC MATERIALS AND METHODS

(Investigation 1 & 2)

The effect of whole leg massage administered at rest

(Investigation 1)

3.3 Subjects

The 10 male subjects (Table 3.1) participating in the study were physically active and free from illness or injury (mean±SD: 24.7±3.4yrs, 77.0±10.0kg, 179.6±7.9cm).

Table 3.1 Age, height, weight and main participation sport of the 10 male subjects participating in Investigation 1.

Subject No.	Age	Height (cm)	Weight (kg)	Main sport
1	20	192	93	Rugby
2	33	186	89	Football
3	21	166	67	Hockey
4	22	179	65	Cycling
5	20	173	70	Hockey
6	20	183	83	Football
7	34	187	82	Swimming
8	19	172	69	Triathlon
9	29	176	70	Triathlon
10	29	182	82	Football

Subjects were requested to refrain from consuming alcohol or caffeinated drinks for 24 hrs prior to the test, and were tested in a 2hr postprandial condition. All treatments were performed in an ambient room temperature of between 21 - 24°C; and each subject completed the three treatment modes in a different order (Table 3.2) to minimise bias. There was a minimum of two days between each treatment. During each testing session, subjects were requested to remain still and quiet throughout (Figure 3.1).

Table 3.2 Randomly assigned treatment methods for each subject for subjects in Investigation 1.

Subject	1	2	3	4	5	6	7	8	9	10
MM	1	2	3	1	3	1	2	2	1	3
VM	2	3	1	3	2	2	3	1	3	2
R	3	1	2	2	1	3	1	3	2	1

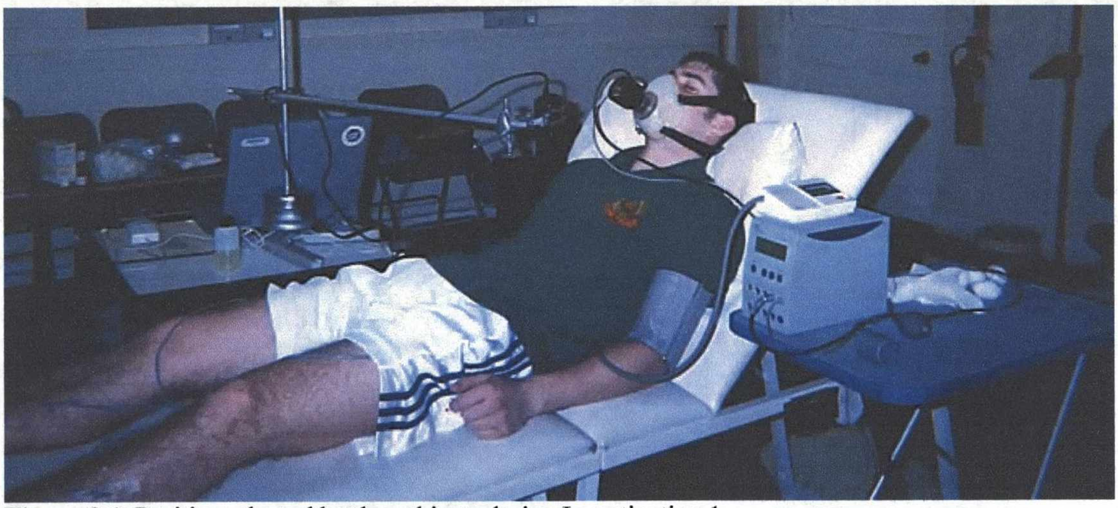


Figure 3.1 Position adopted by the subjects during Investigation 1.

3.4 Treatment Protocols

3.4.1 Manual leg Massage (MM): The posterior aspect of the leg was massaged for 15mins in a prone position, followed by the anterior in a supine position for the same time period. The general sequence of massage (manual and vibratory) is detailed in Table 3.3. Subjects were requested to remain still and quiet throughout

3.4.2 Vibratory leg Massage (VM): The vibratory leg massage was administered using the U-shaped sponge (app. 230) at 30Hz to simulate effleurage, and the 4-ball adaptor (app. 216) at 60Hz to simulate petrissage.

Table 3.3 General sequence of leg massage (manual and vibratory) for prone then supine positions (total time = 30mins).

Prone	Time (min)	Supine	Time (min)
Superficial effleurage of whole leg	1	Superficial effleurage of whole leg	1
Superficial effleurage of hamstrings	0.5	Superficial effleurage of quadriceps	0.5
Deep effleurage of hamstrings	1	Deep effleurage of quadriceps	1
Kneading of hamstrings	1	Kneading of quadriceps	1
Wringing of hamstrings	1	Wringing of quadriceps	1
Superficial effleurage of whole leg	0.5	Superficial effleurage of whole leg	0.5
Deep effleurage of calf	0.5	Deep effleurage of tibialis anterior	0.5
Kneading of the calf	0.5	Kneading of tibialis anterior	0.5
Deep effleurage of whole leg	1	Deep effleurage of whole leg	1
Superficial effleurage of whole leg	0.5	Superficial effleurage of whole leg	0.5

3.4.3 Rest (R): Subjects were required to lay in a prone position for 15mins, and then in a supine position for a further 15mins.

3.5 Data collection

Prior to the baseline measurements, subjects rested for 10mins in a supine position in a quite room at an ambient temperature. Measurements heart rate variability, blood pressure, pulmonary ventilation, oxygen uptake and carbon dioxide production, body temperature, and perception of feeling were taken at rest (baseline), and for five minutes at the end of the 30min treatment. Heart rate is presented as the one minute average from the last minute of data collection.

The effect of single leg calf massage administered at rest (Investigation 2)

3.6 Subjects

Subjects were selected on the basis that they participated regularly (approximately five times a week) in sports which required the use of both legs equally (running, swimming, cycling), and did not participate regularly in sports requiring the prominence of one leg (football), as this has been shown to have a confounding effect on limb venous volume (Boutcher & Boutcher, 2005).

Each of the 10 male subjects (Table 3.4) (mean±SD: age 24.5±4.1yrs, weight 73.6±7.8kg, height 177.7±7.1cm) completed the three recovery modes in a different order (Table 3.5) to minimise bias.

Table 3.4 Age, height, weight and main participation sport of the 10 male subjects participating in Investigation 2.

Subject No.	Age	Height (cm)	Weight (kg)	Main sport
1	20	176.3	75	Triathlon
2	20	174.1	63	Swimming
3	24	169.9	69	Hockey
4	25	184	72	Running
5	30	164	88	Hockey
6	32	185	74	Swimming
7	27	187	86	Cycling
8	22	177.3	68	Cycling
9	23	179.1	69	Swimming
10	22	180.7	72	Hockey

Table 3.5 Randomly assigned treatment order for each subject in Investigation 2.

Subject	1	2	3	4	5	6	7	8	9	10
R	1	2	3	1	3	1	2	2	1	3
MM	2	3	1	3	2	2	3	1	3	2
VM	3	1	2	2	1	3	1	3	2	1

3.7 Treatment Protocols

3.7.1 Manual leg massage (MM): The 10min manual massage was administered to the right calf with the subject in a prone position. On completion, subjects were requested to turn into a supine position. The general sequence of manual massage for all the subjects during the 10min treatment can be seen in Table 3.6.

3.7.2 Vibratory leg massage (VM): The vibratory leg massage was administered using the round sponge (app. 210) at 30Hz to simulate effleurage, and the 4-ball adaptor (app. 216) at 60Hz to simulate petrissage.

Table 3.6 General sequence of the 10mins calf massage (manual and vibratory) during Investigation 2

General sequence	Time (mins)
Superficial effleurage of the lower leg	2.5
Deep effleurage of calf	2.5
Kneading of calf	3
Deep effleurage of calf	1
Superficial effleurage of lower leg	1

3.7.3 Rest (R): Subjects were required to lay in a prone position for 10mins.

3.8 Data collection

The protocol for heart rate, heart rate variability, blood pressure, rate pressure product, body temperature, and perception of feeling data collection are explained in Chapter 2. A specific method used during this investigation was:-

3.8.1 Calf circumference (CC): Changes in calf circumference was used as an indication of limb venous volume. CC was measured at the maximum point of the calf by an experienced technician using a non-stretch flexible tape and marked with a permanent pen. A line was drawn at the point of maximum circumference and measured from the popliteal crease and inferior patella in order to correctly identify the site during the subsequent tests, and minimise error.

3.9 Timeline of measurements

The baseline measurements were taken with the subject lying in a supine position. Prior to the measurements, subjects rested for 10mins in a supine position in a quite room at an ambient temperature.

Measurements of heart rate, blood pressure, limb blood flow, calf circumference, body temperature, and perception of feeling were taken at baseline; on completion of the treatment (0mins); and at the end of a post recovery 10min period. HRV was taken during the last 5mins of the treatment, and during the last 5mins of the post treatment recovery period.

3.10 Statistical Analysis (Investigation 1 & 2)

Parametric data are presented as Mean ± Standard deviation (SD). Prior to testing the experimental hypotheses, Shapiro-Wilks normality test and Levene's homogeneity of variance test were performed on all data; these checks revealed satisfactory outcomes for all variables apart from the heart rate variability and limb blood flow data, which was not normally distributed. Repeated measures ANOVA and *post hoc* paired samples *t*-tests were performed to compare effects between conditions. Paired *t*-test analysis was also used to compare post treatment to baseline. Non-parametric data (perception of feeling) are presented as Median ± InterQuartile Range (IQR). The perception of feeling heart rate variability and limb blood flow data were analysed with Friedman's test, and *post hoc* with Wilcoxon's signed-rank test in order to compare effects between conditions. For correlation analysis, Pearson's bivariate correlation coefficient analysis was calculated. The level of significance was taken as $p<0.05$.

RESULTS

The effect of whole leg massage administered at rest (Investigation 1)

3.11 The effect of whole leg massage on heart rate and heart rate variability

From an initial baseline of 70.3±7.6bpm, HR for MM and VM decreased to 63.7±7.1bpm and 65.4±6.7bpm respectively at the end of the 30mins massage. The HR for R remained constant, and at the end of the 30mins HR was 71.5±7.6bpm, which was significantly higher than MM. Figure 3.2 demonstrates that for MM and VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

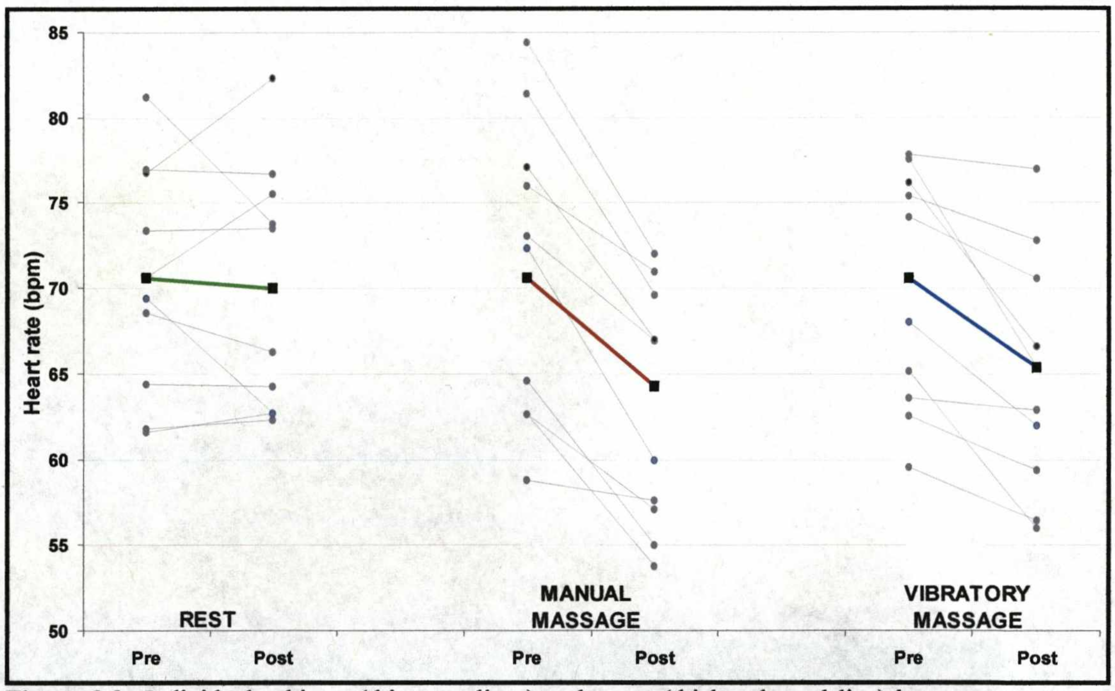


Figure 3.2 Individual subjects (thin grey lines) and mean (thick coloured line) heart rate response following 30mins of Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10).

There was a significant decrease in the indicators of sympathetic heart control for MM at the end of the 30mins compared to R (LFnorm p=0.013 and LF:HF ratio p=0.019) (Table 3.7). There was no significant difference between VM and MM.

Furthermore there was a significant increase in indicators of parasympathetic heart control for MM at the end of the 30mins compared to R (RMSSD p=0.028, pNN50

p=0.017 and HFnorm p=0.035). There was no significant difference between VM and MM.

Table 3.7 Heart Rate Variability (time and frequency domain) response following 30mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10). Significant differences ***a*** = MM *vs* R. Parasympathetic, Sympathetic and Sympathovagal indicators.

	Baseline	Rest End of 30mins treatment	Manual Massage End of 30mins treatment		Vibratory Massage End of 30mins treatment
Heart Rate	70.3 ± 7.6	71.5 ± 7.6	63.7 ± 7.1	a	65.4 ± 6.7
LF norm	65.6 ± 11.2	67.7 ± 6.5	56.3 ± 8.2	a	61.1 ± 6.9
LF:HF Ratio	2.05 ± 1.2	2.10 ± 0.6	1.50 ± 0.7	a	1.82 ± 0.5
HF norm	34.4 ± 11.2	32.3 ± 6.5	43.7 ± 8.2	a	38.9 ± 6.9
RMSSD:	46.6 ± 18.5	54.8 ± 15.1	48.2 ± 12.7	a	51.2 ± 16.0
pNN50:	6.9 ± 3.5	7.3 ± 4.7	14.1 ± 8.1	a	14.9 ± 9.6

Figure 3.3 demonstrates that for MM and VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

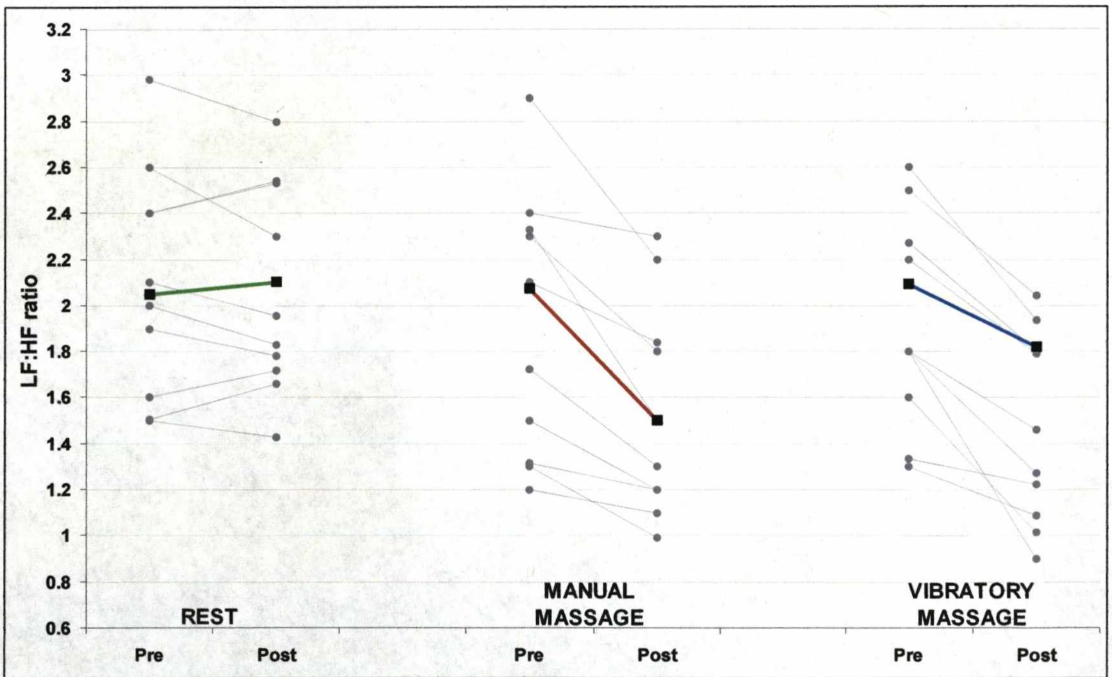


Figure 3.3 Individual subjects (thin grey lines) and mean (thick coloured line) sympathovagal (LF:HF ratio) response following 30mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10).

In summary, VM and MM are equally effective at decreasing cardiac sympathetic and increasing parasympathetic drive, thus contributing to a relaxation effect.

3.12 The effect of whole leg massage on systolic & diastolic blood pressure

Baseline measurement of systolic blood pressure was 116.9±6.5mmHg. SBP then decreased to 112.1±5.7mmHg (MM) and 113.3±6.3mmHg (VM), but remained constant at 116.1±4.8mmHg for R (Table 3.8). Baseline diastolic blood pressure was 72.1±4.2mmHg. DBP remained relatively constant throughout (MM (69.6±3.4mmHg), VM (71.8±4.1mmHg) or R (72.3±5.8mmHg)) and there was no significant difference evident between the conditions.

In summary, there was no significant difference between the three conditions for systolic or diastolic blood pressure.

3.13 The effect of whole leg massage on rate pressure product

Baseline RPP was 8218±444units (Table 3.8). The values for MM (7154±502 units; p=0.001) and VM (7339±470units; p=0.013) were significantly lower than R (8126±488units) at the end of the 30mins, which equated to being 11.9% (MM) and 9.7% (VM) lower. At the end of the 30mins, RPP for MM and VM were similar, and both were significantly lower than baseline.

3.14 Interaction between RPP and HR/SBP following a whole leg massage

A reduction in rate pressure product has been shown to be related more to a decrease in HR than SBP (Herminda *et al.*, 2001). This was confirmed during the present study, where RPP correlated highly with HR (r^2 = 0.8387), and not so highly with SBP (r^2 = 0.3023) (Figure 3.4). The data presented is pooled data from the three conditions for all time points. In addition, the response was similar for individual conditions; for example for manual massage RPP correlated highly with HR (r^2 = 0.8888), and not so highly with SBP (r^2 = 0.3005).

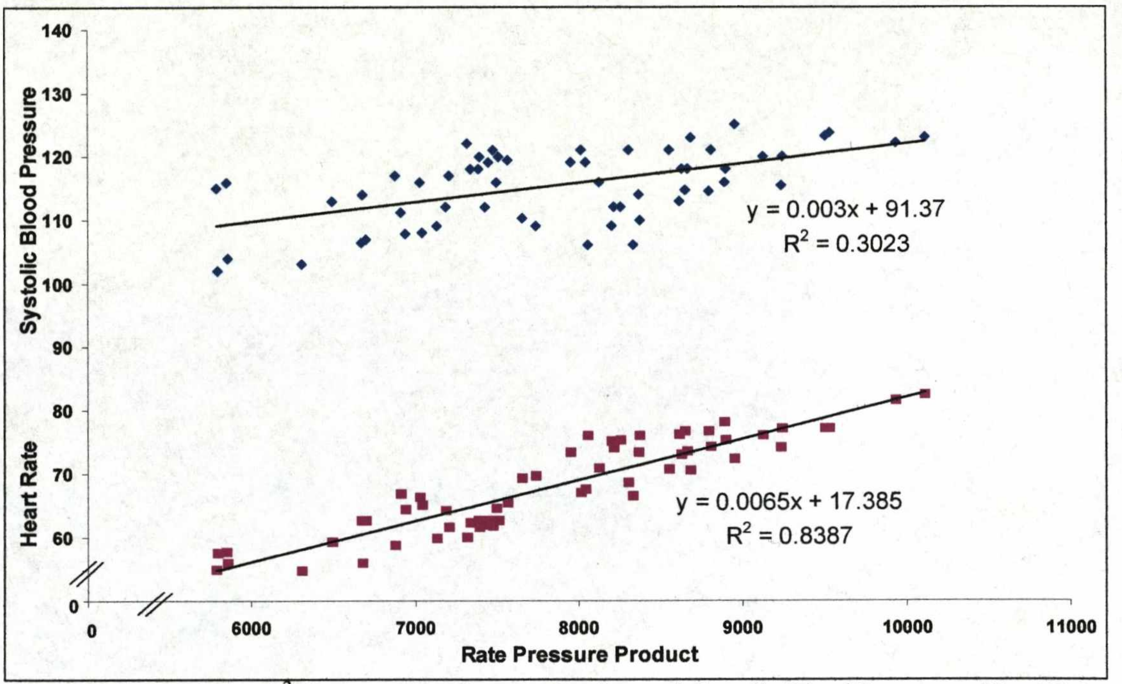


Figure 3.4 Correlation (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.

3.15 The effect of whole leg massage on pulmonary ventilation

3.15.1 Respiratory rate: Baseline respiratory rate was 14.8±1.2 cycles · min^{-1} (Table 3.8). Following the 30mins leg massage there was significant decrease in rate to 13.6±3.0cycles · min^{-1} (MM p=0.002) and 13.8±2.7cycles · min^{-1} (VM p=0.007) compared to R (15.0±2.3cycles · min^{-1}). Furthermore, at the end of 30mins respiratory rate for MM (p=0.040) and VM (p=0.048) were both significantly lower from baseline. There was no significant difference between MM and VM.

3.15.2 Tidal volume (V_T): Baseline tidal volume was 0.39±0.09litres (Table 3.8). V_T for R decreased to 0.38±0.08litres, but increased to 0.42±0.09litres for MM and 0.41±0.07litres for VM. No significant difference was seen between the three conditions.

3.15.3 Pulmonary ventilation: Baseline pulmonary ventilation was 5.77±0.73l · min^{-1} (Table 3.8). There was no significant difference between the three conditions at the end of treatment.

In summary, MM and VM were equally effective at significantly increasing respiratory rate and decreasing tidal volume compared to R. Pulmonary ventilation was unaffected by either massage condition.

3.16 The effect of whole leg massage on metabolic rate

3.16.1 Oxygen uptake and carbon dioxide output: Baseline oxygen uptake and carbon dioxide output were 4.2±0.21 ml kg^{-1} min^{-1} and 3.4±0.23 ml kg^{-1} min^{-1} respectively (Table 3.8). Both variables remained stable throughout for all conditions. By the end of 30mins there was no significant difference between the conditions for oxygen uptake (R (4.14±0.18 ml kg^{-1} min^{-1}), MM (4.15±0.18 ml kg^{-1} min^{-1}) and VM (4.16±0.27 ml kg^{-1} min^{-1})), and for carbon dioxide output (R (3.39±.24 ml kg^{-1} min^{-1}), MM (3.4±0.18 ml kg^{-1} min^{-1}) and VM (3.37±0.22 ml kg^{-1} min^{-1})). Massage, either manual or vibratory had no significant effect on oxygen uptake or carbon dioxide output.

3.17 The effect of whole leg massage on leg skin temperature (Leg_{Temp}) and aural temperature

3.17.1 Leg_{Temp} response: Baseline leg skin temperature was 31.5±0.5°C (Table 3.8). Following 30mins, Leg_{Temp} for R remained constant (31.5±0.4°C). For MM and VM there was as increase in Leg_{Temp}, and at the end of the 30mins, Leg_{Temp} was 33.4±0.33°C for MM and 34.0±0.4°C for VM; both were significantly higher than R (MM p=0.00008 and VM p=0.00002). In addition, MM and VM were both significantly higher than baseline.

3.17.2 $Aural_{Temp}$ response: Baseline measurement of $Aural_{Temp}$ was 36.5±0.3°C (Table 3.8). At the end of the 30mins, $Aural_{Temp}$ for MM and VM had increased significantly from baseline to 36.9±0.3°C and 37.3±0.3°C respectively; both were significantly higher than R (MM & VM p<0.001) where the temperature remained constant (36.5±0.3°C).

3.18 The effect of whole leg massage on perception of feeling

Baseline perception of feeling (PoF) was 2 (IQR 1.25, 3). Feeling improved over the 30mins period for both massage conditions; and at the end of the 30mins the perception of feeling for MM was 5.5 (IQR 5, 6) and 5 (IQR 4.5, 5.75) for VM (Table 3.8). This was significant higher (MM p=0.005 and VM p=0.012) than R (2 (IQR 1.25, 3)). In contrast to R, the 30mins PoF for the massage conditions was significantly higher compared baseline (MM p=0.006 and VM p=0.015). The results indicate that MM and VM were equally effective at increasing mood state and promoting relaxation.

Table 3.8 Respiratory variables, oxygen uptake, carbon dioxide production, leg skin temperature, aural temperature and perception of feeling following 30mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=10). All data are presented as Mean±Std apart from perception of feeling which is presented as Median±Interquartile range. Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R and ***d*** = 30mins post treatment *vs* baseline (R).

	Baseline	**End of 30mins treatment**		
		R	**MM**	**VM**
Respiratory rate (cycles $\cdot$ min^{-1})	14.8±3.5	15.0±2.3	13.6±3.0***ad***	13.8±2.7***bd***
Tidal volume (litres)	0.39±0.09	0.38±0.08	0.42±0.09	0.41±0.7
Pulmonary ventilation (l $\cdot$ min^{-1})	5.77±0.73	5.68±0.85	5.72±0.93	5.66±0.84
Oxygen uptake (ml $\cdot$ kg^{-1} $\cdot$ min^{-1})	4.16±0.19	4.14±0.18	4.15±0.18	4.16±0.27
Carbon dioxide output (ml $\cdot$ kg^{-1} $\cdot$ min^{-1})	3.38±0.20	3.39±0.24	3.4±0.18	3.37±0.22
Leg skin temperature (°C)	31.5±0.48	31.5±0.45	33.5±0.39***ad***	3.34.0±0.33***bd***
Aural temperature (°C)	36.5±0.29	36.5±0.32	36.9±0.34***d***	37.3±0.31***ad***
Perception of feeling	2.0 (1.25, 3)	2.0 (1.25, 3)	5.5 (5, 6)***ad***	5.0 (4.5, 5.75)***bd***

The effect of single leg calf massage administered at rest (Investigation 2)

3.19 The effect of calf massage on heart rate and heart rate variability

Baseline HR was 67.3±8.7bpm (Table 3.9). The HR for R remained relatively constant throughout, and HR was 66.7±11.5bpm and at the end of the 10mins additional rest was 66.8±11.2bpm. There was no significant difference between the response for MM and VM, and at the end of the 10min treatment HR had decreased to 59.5±10.9bpm (MM) and 63.0±12.2bpm (VM). By the end of the 10mins additional rest period HR for MM and VM were 61.1±12.7bpm and 62.9±10.9bpm respectively.

Figure 3.5 demonstrates that for MM and VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

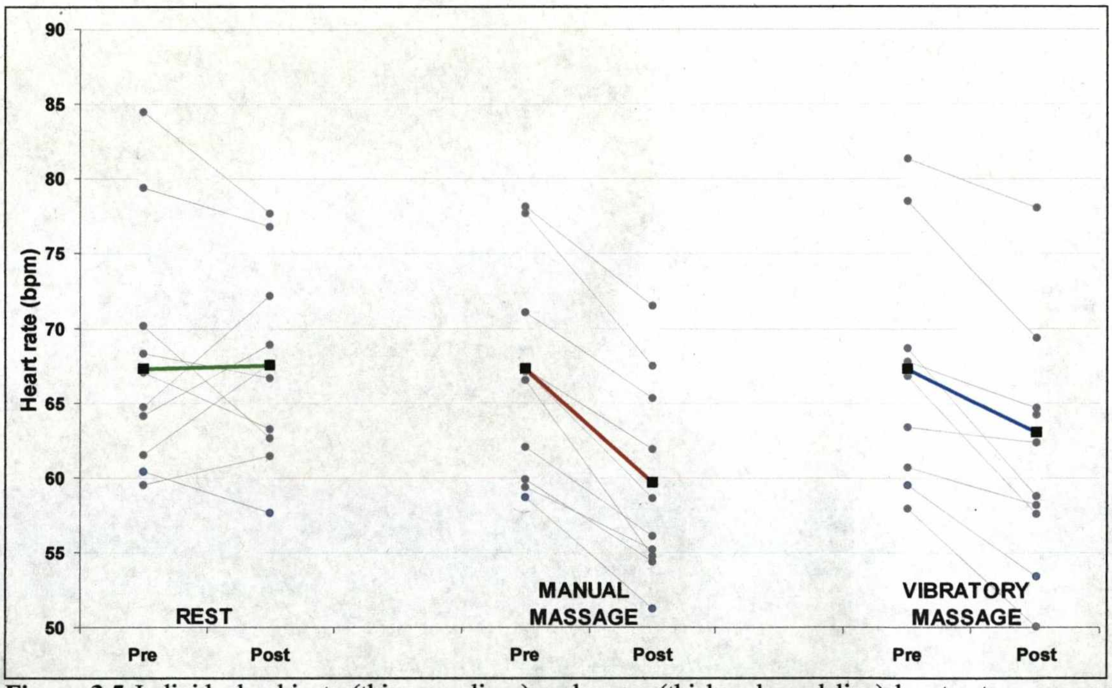


Figure 3.5 Individual subjects (thin grey lines) and mean (thick coloured line) heart rate response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).

At the end of treatment the indicators of sympathetic heart control for MM were significantly lower compared to R (Table 3.9) (LFnorm p=0.009; and LF:HF ratio p=0.015). This effect continued to the end of the additional 10mins recovery period (LFnorm p=0.041; LF:HFratio p=0.044). There was no significant difference between the HR response for MM and VM. Furthermore, there was no significant difference seen between R and VM at the end of 10mins treatment (LFnorm p=0.087 and LF:HF ratio p=0.069), or at the end of the additional 10mins recovery period (LFnorm p=0.29 and LF:HF ratio p=0.41).

At the end of 10mins treatment the indicators of parasympathetic heart control for MM were significantly higher than for R (RMSSD p=0.011; pNN50 p=0.022; HFnorm p=0.019), which continued to the end of the additional 10mins rest period (HR p=0.020; RMSSD p=0.019; pNN50 p=0.033). There was no significant difference seen between R and VM at the end of 10mins treatment (HR p=0.093; LFnorm p=0.081; LF:HFratio p=0.099). No difference was seen at the end of the additional 10mins recovery period (HR p=0.078; LFnorm p=0.11; LF:HFratio p=0.081). There was no significant difference between the HR response for MM and VM.

Table 3.9 Heart Rate Variability (time and frequency domain) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10). Significant difference ***a*** = MM *vs* R. **Parasympathetic**, **Sympathetic** and **Sympathovagal** indicators.

	Baseline	Rest After 10mins treatment	Manual massage After 10mins treatment		Vibratory massage After 10mins treatment
HR	67.3 ± 8.7	66.7 ± 5.3	59.4 ± 8.8	a	63.0 ± 11.1
LF norm	72.0 ± 9.2	71.6 ± 6.1	62.1 ± 9.4	a	66.1 ± 9.0
LF:HF Ratio	2.9 ± 1.3	2.64 ± 0.6	1.79 ± 0.7	a	2.15 ± 0.9
HF norm	28.0 ± 9.2	28.4 ± 6.1	37.9 ± 9.4	a	33.9 ± 9.0
RMSSD	34.9 ± 24.8	36.5 ± 10.7	67.9 ± 19.5	a	64.2 ± 23.4
PNN50	6.9 ± 2.1	7.8 ± 2.5	18.3 ± 8.5	a	15.3 ± 7.4
		Rest 10mins rest	**Manual massage** 10mins rest		**Vibratory massage** 10mins rest
HR		66.8 ± 11.2	61.1 ± 12.7	a	62.9 ± 10.9
LF norm		73.3 ± 7.8	63.1 ± 11.6	a	69.7 ± 10.1
LF:HF Ratio		2.75 ± 1.1	2.17 ± 1.4	a	2.43 ± 1.2
HF norm		26.7 ± 7.8	36.9 ± 11.6	a	30.3 ± 10.1
RMSSD		34.1 ± 19.4	54.8 ± 18.9	a	61.1 ± 19.4
PNN50		6.7 ± 3.2	15.7 ± 6.1	a	13.9 ± 4.5

Figure 3.6 demonstrates that for MM and VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

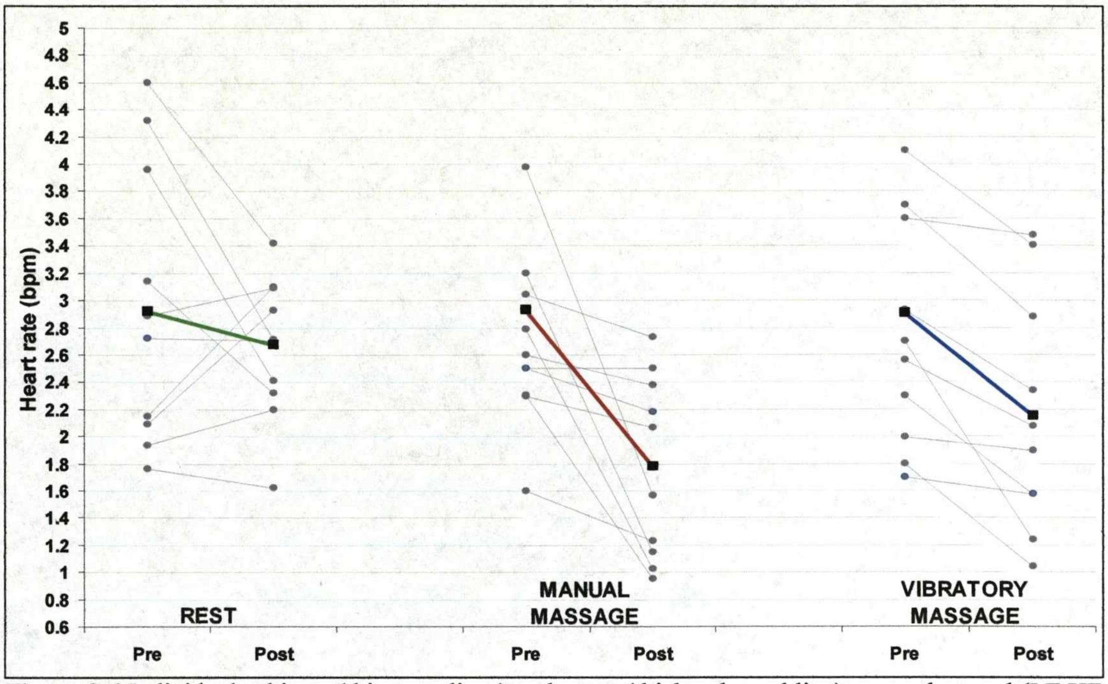


Figure 3.6 Individual subjects (thin grey lines) and mean (thick coloured line) sympathovagal (LF:HF ratio) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).

In summary, sympathovagal activity remained unchanged with Rest, whereas MM and VM are effective at decreasing cardiac sympathetic and increasing parasympathetic drive, thus inducing a relaxation effect following a 10mins calf massage.

3.20 The effect of calf massage on blood pressure (systolic and diastolic)

3.20.1 Systolic blood pressure: Baseline systolic blood pressure was 114.0±11.8mmHg. At the end of the 10mins calf massage there was no significant difference between the methods (110.4±11.5mmHg (R), 107.2±10.6mmHg (MM) and 106.4±10.4mmHg (VM)). At the end of the additional 10mins rest SBP was 108.5±9.4mmHg (R), 105.7±10.4mmHg (MM) and 107.2±11.3mmHg (VM) (Table 3.10). There was no significant difference between MM and VM.

3.20.2 Diastolic blood pressure: Baseline diastolic blood pressure was 65.2±7.1mmHg. At the end of the 10mins calf massage DBP remained stable (R 64.4±5.1mmHg; MM 64.7±6.7mmHg and VM 65.2±5.4mmHg) and there was no significant difference seen between the massage conditions and R. At the end of additional 10mins rest DBP remained constant for all conditions. There was no significant difference between MM and VM.

In summary, there was no significant difference between the three conditions for systolic or diastolic blood pressure.

Table 3.10 Systolic and diastolic blood pressure (mmHg) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).

		R	MM	VM
Systolic blood pressure	**Baseline**	114.0±11.8mmHg		
	End of 10mins treatment	110.4±11.5mmHg	107.2±10.6mmHg	106.4±10.4mmHg
	End of 10mins rest period	108.5±9.4mmHg	105.7±10.4mmHg	107.2±11.3mmHg
		R	**MM**	**VM**
Diastolic blood pressure	**Baseline**	65.2±7.1mmHg		
	End of 10mins treatment	64.4±5.1mmHg	64.7±6.7mmHg	65.2±5.4mmHg
	End of 10mins rest period	64.4±5.0mmHg	64.7±6.7mmHg	66.7±5.4mmHg

3.21 The effect of a calf massage on rate pressure product

Baseline RPP was 7672±499units, and for Rest RPP had decreased to 7328±487units at the end of 10mins treatment. This also remained below the baseline level (7245±476units) at the end of the additional 10mins rest.

For MM (6376±502units) and VM (6703±469units), post treatment RPP was significantly lower than Rest (MM p=0.003; VM p=0.010) which persisted to the end of the 10mins additional rest; at this point RPP for MM was 6460±541units and 6744±612units for VM, and were not significantly different.

The results indicate that both MM and VM were effective at decreasing rate pressure product.

3.22 Interaction between RPP and HR/SBP following a whole leg massage

This results of the present investigation showed that RPP correlated highly with HR (r^2 = 0.8052), and not so highly with SBP (r^2 = 0.4164) (Figure 3.7). The data presented is pooled data from the three conditions for all time points.

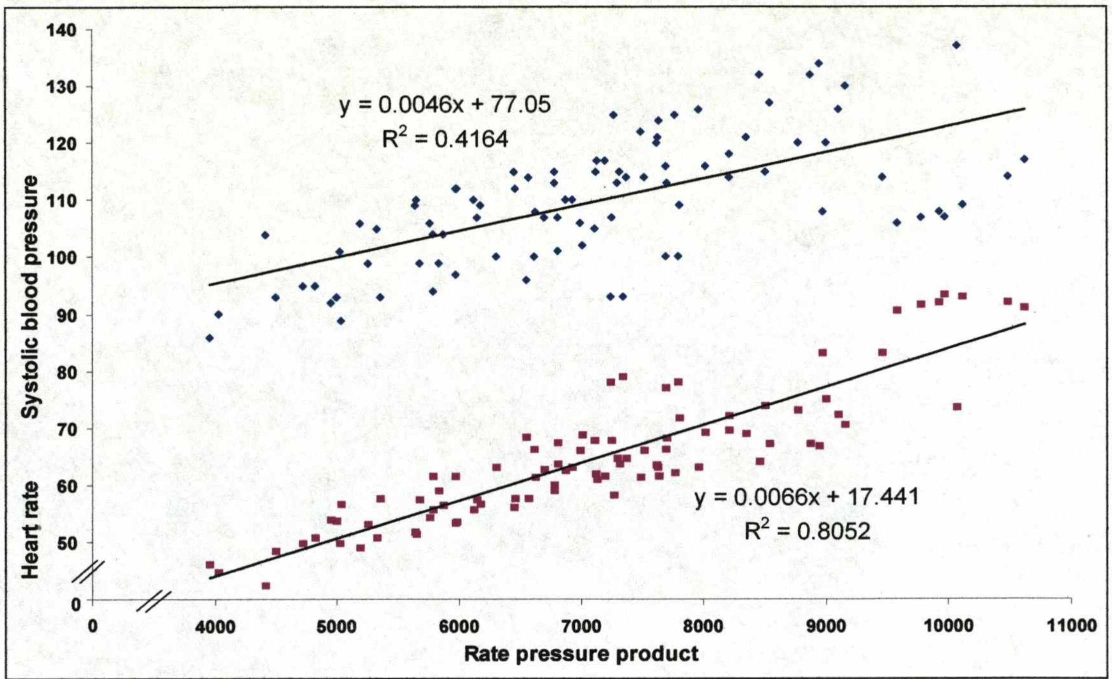


Figure 3.7 Correlation (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.

3.23 The effect of a calf massage on leg skin and aural temperature

3.23.1 Leg Temperature (Leg_{Temp}): Temperature was measured from both the right leg (treated) and left leg (untreated control) for the massage conditions. Baseline leg skin temperature was 31.4±0.5°C (Table 3.11). For the untreated control limb, Leg_{Temp} remained constant throughout the treatment period (R 31.4±0.4°C; MM 31.6±0.5°C; and VM 31.6±0.6°C), and also at the end of the 10mins additional rest period (Leg_{Temp} was 31.4±0.5°C (R), 31.4±0.3°C (MM) and 31.5±0.5°C (VM)).

For the treated leg (right), Leg_{Temp} increased immediately with the administration of the manual or vibratory massage. At the end of the 10mins calf treatment Leg_{Temp} was 32.9±0.4°C for MM and 33.7±0.6°C for VM; significantly higher than R (MM p=0.0001 and VM p=0.00009). At the end of the additional 10mins rest period Leg_{Temp} had decreased somewhat, but remained significantly higher than R (MM (32.2±0.7°C; p=0.0078) and VM (33.1±0.6°C; p=0.0024)). The treated leg skin temperature for VM was significantly higher than MM.

Table 3.11 Leg skin temperature (°C) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10) Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, ***c*** = MM *vs* VM, and ***d*** = 10mins post treatment *vs* baseline.

	R	MM (treated)	MM (untreated)	VM (treated)	VM (untreated)
Baseline	31.4±0.5°C				
End of 10mins treatment	31.5±0.2°C	32.9±0.2°C***a***	31.6±0.1°C	33.7±0.4°C ***bc***	31.6±0.2°C
End of 10mins rest period	31.4±0.2°C	32.2±0.4°C ***ad***	31.4±0.2°C	33.1±0.3°C ***bcd***	31.5±0.3°C

3.23.2 Aural temperature (Aural$_{Temp}$): Baseline measurement of Aural$_{Temp}$ was 36.7±0.1°C (Table 3.12). At the end of the 10mins treatment Aural$_{Temp}$ for MM and VM had increased to 37.1±0.3°C and 37.3±0.2°C respectively; this contrasted with R where the temperature remained constant. At the end of the additional 10mins rest, Aural$_{Temp}$ for R did not change (36.7±0.3°C), and the Aural$_{Temp}$ for MM and VM were 36.9±0.1°C and 37.0±0.1°C respectively, and not significantly different between the conditions.

Table 3.12 Aural temperature (°C) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10). Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, and ***d*** = VM 10mins post treatment *vs* baseline.

	R	MM	VM
Baseline	33.1±0.41°C		
End of 10mins treatment	33.3±0.36°C	33.6±0.45°C***a***	33.8±0.30°C***b***
End of 10mins rest period	33.2±0.35°C	33.6±0.40°C	33.7±0.38°C***d***

3.24 The effect of a calf massage on the estimation of limb blood flow

Baseline estimation of limb blood flow was 0.23±0.06*AU* (Table 3.13). LBF was measured immediately on completion of the 10mins calf massage. At the end of treatment, LBF for R was 0.23±0.05*AU*, and at the end of the additional rest period was 0.22±0.05*AU*. A similar response was seen for MM and VM, were there was no significant difference between the untreated (ut) and treated (t) limb at the end of 10mins treatment (MM (t) 0.23±0.06*AU* *vs* (ut) 0.23±0.05*AU*) (VM (t) 0.23±0.06*AU* *vs* (ut) 0.22±0.05)). This was also the case at the end of the additional 10mins rest period (MM (t) 0.23±0.06AU *vs* (ut) 0.23±0.07AU) and (VM (t) 0.23±0.05AU *vs* (ut) 0.23±0.05AU)).

Table 3.13 Estimation of limb blood flow (AU) response following 10mins Rest (R), Manual calf massage (MM) and Vibratory calf massage (VM) (n=10).

	R	MM (treated)	MM (untreated)	VM (treated)	VM (untreated)
Baseline	0.23±0.06AU				
End of 10mins treatment	0.23±0.05AU	0.23±0.06AU	0.23±0.05AU	0.23±0.06AU	0.22±0.05AU
End of 10mins rest period	0.22±0.04AU	0.23±0.06AU	0.23±0.07AU	0.23±0.05AU	0.23±0.05AU

The results indicate that neither MM nor VM had an effect on limb blood flow following a 10min calf treatment.

3.25 The effect of a calf massage on calf circumference

There was no significant difference between the two legs at baseline. The baseline measurement of CC was 37.7±0.9cm for the untreated leg and 38.6±0.8cm for the treated leg (Table 3.14), with the variation being due to the expected anatomical variation between the limbs. At the end of the 10mins treatment period, CC was not significantly different between the three conditions; which was also the case at the end of the additional 10mins rest period. There was no significant difference between the treated and untreated leg for MM or VM at the end of recovery, or between the massage conditions and R.

Table 3.14 Calf circumference (cm) response following 10mins Rest (R), manual calf massage (MM) and Vibratory calf massage (VM) (n=10).

	R	MM (treated)	MM (untreated)	VM (treated)	VM (untreated)
Baseline	38.6±0.8cm (treated) and 37.7±0.9cm (untreated)				
Post treatment	38.3±0.8cm	38.5±0.7cm	37.8±0.8cm	38.7±0.4cm	37.9±0.4cm
End of 10mins rest	38.3±0.4cm	38.7±0.4cm	37.7±0.7cm	38.7±0.6cm	37.8±0.9cm

3.26 The effect of a calf massage on perception of feeling

Baseline PoF was 4.0 (IQR 2.25, 6.0) ‘Good’. There was a decrease in PoF for R to 3 (IQR 2.0, 5.5) at the end of 10mins treatment; with this being maintained to the end of the additional 10mins rest period. For VM, subjects recorded the identical PoF throughout the treatment, and at the end of the 10mins additional rest period (4.0 IQR 0.5, 1.75). MM had the greater effect compared to VM, enhancing PoF to 5.5 (IQR 5.0, 6.0) at the end of treatment, which was significantly higher than R (p=0.017). The results indicate that MM had the greater effect on PoF when compared to VM, enhancing mood state and promoting relaxation.

DISCUSSION

3.27 The effect of leg massage on cardiac autonomic activity

Sensory stimulation has been associated, in healthy subjects, with alterations in both the sympathetic and parasympathetic nervous system depending on the type, location, duration and intensity of massage (Cambron, Dexheimer & Coe, 2006). The results of this present study suggest that leg massage (manual or vibratory) were effective compared to Rest at increasing HRV and parasympathetic activity, and decreasing sympathetic activity, irrespective of treatment duration. This was demonstrated with a decrease in HR, LFnorm, and LF:HFratio; and an associated increase in RMSSD, pNN50 and HFnorm activity. As there was a very similar effect between manual and vibratory massage, they will be discussed collectively.

Both HR and BP decreased following MM and VM. These effects may be considered a sign of relaxation, but the mechanism would be unknown as alterations of heart rate can be caused by a combination of factors. (Kotona, McLean, Dighton & Guz, 1982). The purpose of the measure of HRV was to determine the exact mechanism behind sympathovagal balance, be it a decrease in sympathetic activity and/or an increase in parasympathetic activity.

In the present investigations, the change in sympathovagal balance and consequent significant change in HR and RPP was due to a combination of sympathetic withdrawal and vagal increase. Although purely speculative (and direct measurement being beyond the scope of this study), this reduction would possibly be mediated by a decrease in adrenaline and noradrenaline, which would reduce the sympathetic influence upon the sinoatrial node and arterioles, which in turn would cause an increase in heart rate variability, and decrease in heart rate, blood pressure and rate pressure product.

The magnitude varied according to the type of massage, with the LF:HFratio being lower during MM compared to VM, presumably indicating increased vagal drive. It was also apparent that an increased duration of massage did not have a greater effect on relaxation; indeed the opposite was true. On completion of the 10mins calf massage, LF:HFratio had decreased 38.3%, but during the 30mins whole leg massage had only decreased 21.5%.

During the present investigations, a sampling time of 5mins was used for the short term collection of R-R interval data. This time period has been deemed a valid and reliable duration for short term recordings, providing the heart rate is stable (TaskForce, 1996). Although inter-subject variability was considerable (estimated from the standard deviation), intra-subject variations were not (as shown by the individual data), and therefore the HRV data was deemed as a valid and reliable reflection of cardiac autonomic activity (Sinnereich *et al.*, 1998; Højgaard, Holstein-Rathlou, Agner & Kanters, 2005; Sandercock, Bromley & Brodie, 2005; & Kobayashi, 2007).

The only other studies which have reported the effect of massage on HRV have treated the neck, head, shoulders, and back. Delaney, Leong, Watkins & Brodie (2002) and McNamara, Burnham, Smith & Carroll (2003) massaged the neck as part of the therapy regimen. The location of the massage would necessitate the linear stroking of the sternocleidomastoid muscle (Cambron, Dexheimer & Coe, 2006). This may cause the mechanical deformation of the carotid sinus (located at the bifurcation of the common carotid artery), causing afferent impulses by the carotid sinus and vagus nerves to the nuclei tractus solitarius and the para median nucleus in the brain stem (Tortora, 2005), leading efferent impulses through the sympathetic and vagus nerves to the heart and blood vessels, decreasing heart rate and blood pressure (European Society of Cardiology, 2004).

Using a similar technique McNamara, Burnham, Smith & Carroll (2003) reported an increase in parasympathetic activity compared to baseline; however, the result may have be confounded by the fact that immediately following the massage treatment, the subjects were to receive a diagnostic cardiac catheter.

In conclusion, both manual and vibratory massage were effective at decreasing cardiac sympathetic and increasing parasympathetic activity, thus reducing heart rate during the 30min whole leg manual massage (Investigation 1), or 10min calf massage (Investigation 2).

3.28 The effect of leg massage on blood pressure and rate pressure product

The effect of massage on blood pressure can be mediated by both physiological and psychological factors (Aourell, Skoog & Carleson, 2003), and a decrease in sympathetic drive could result in an increase in arteriole vasodilatation, and cause a decrease in heart rate and cardiac output. (Weerapong, Hume & Koly, 2005). The majority of research into the effect of massage on blood pressure reduction has focussed on the effect of neck, shoulders and back massage, and not leg massage. In the present investigations, massage did not have any significant effect on systolic or diastolic blood pressure compared to Rest, although both variables did decrease.

Delaney, Leong, Watkins & Brodie (2002) reported a significant reduction in both SBP and DBP following a 20min massage of the neck, shoulder and head. A similar effect was reported by Barr & Taslitz (1971), Corley, Ferriter, Zeh, Gifford (1995), Cady & Jones (1997), Hernandez-Reif *et al.*, (2000), McNamara, Burnham, Smith & Carroll (2003) and Cambron, Dexheimer & Coe (2006), decreasing blood pressure both in the short and long term. However, these long term changes in blood pressure reported by Cambron, Dexheimer & Coe (2006) were more to do with a change in lifestyle factors, rather than an accumulative effect of massage.

Rate pressure product is the surrogate measure of myocardial oxygen uptake and cardiac power (Herminda *et al.*, 2001) and could be considered a further index of sympathovagal balance. In the present investigations, RPP was seen to be significantly lower than Rest during both massage conditions (manual and vibratory).

Data extrapolated from Delaney, Leong, Watkins & Brodie (2002) showed that as RPP decreased, sympathovagal balance also decreased (Table 3.15). A comparable effect was evident in the present investigation where RPP, following a 30min leg massage, decreased by 14.8%, whereas sympathovagal (LF:HF ratio) balance decreased 27.3%. Furthermore, following a 10mins calf massage RPP decreased 16.9% and LF:HFratio decreased 38.2%.

Table 3.15 Rate pressure product and LF:HFratio data pre and post 20mins head, neck and shoulder massage. Data from Delaney, Leong, Watkins & Brodie (2002).

	Rate pressure product	LF:HF Ratio
Pre massage	8987.5	1.5
Post massage	7913.5 (-11.9%)	1.3 (-17.1%)

In conclusion, the massage conditions (manual or vibratory) had no effect on blood pressure (systolic or diastolic) compared to Rest. However, due to the decrease in heart rate there was a net decrease on rate pressure product, indicating a possible parasympathetic effect. The results also indicate that in the absence of a measure of HRV, RPP may provide a rudimentary indication of sympathovagal balance.

3.30 The effect of leg massage on respiration and metabolic rate

This is the first study to investigate the effect of mechanical vibratory leg massage on metabolic rate and pulmonary function. The lack of effect of massage, either manual or vibratory on oxygen uptake was not unexpected, as energy expenditure is directly related to the amount of work performed by the muscles (McArdle, Katch & Katch, 2007). As there is no kinetic exertion, other than the passive rhythmic effect of kneading and stroking the skin, and as manual massage does not elicit any muscle contraction (Hendrickson, 2003) only a slight pulling effect against the muscle attachments (Hayter, Coombes, Knez & Brancato, 2005), the amount of 'work' completed is negligible and therefore would not increase oxygen uptake.

The results of the present investigation support the work of Boone & Copper (1995) who manually massaged the anterior and posterior aspects of both legs for 30mins. They noted that the treatment had no significant effect on oxygen uptake when compared to the control passive resting state. Boone & Cooper (1995) also studied cardiac output, where they noted no significant difference; however, they observe a decrease in HR, which caused a concomitant increase in stroke volume. The decrease in HR in this present investigation was more pronounced than the aforementioned study by Boone & Cooper (1995).

The conclusions of the present investigations are contrary to a previous study by Pocklington & Repovich (2002) who report an increase in VO_2 during a 60mins massage, and an increase in metabolic rate which would indicate a sympathetic response (Beary, Benson, Klemchuk, 1974). However, other variables including HR and BP decreased, indicating a parasympathetic effect. Also, the results of this study are not directly comparable, as the Pocklington & Repovich (2002) study involved massage of the whole body for 60mins, double the time period of Investigation 1.

In addition, oxygen uptake did not increase during mechanical vibratory massage, despite previous research suggesting that mechanical vibrations elicit reflex contractions within the muscle structure (Cardinale & Lim, 2003), and affect the neuromuscular system, causing a modification in the functional capacity of the skeletal muscle (Cardinale & Bosco, 2003). If this were the case, an increase might be expected, but this did not occur. In this study, the vibratory massage was set at 30Hz to simulate effleurage, and 60Hz to simulate petrissage. Previous research by Cardinale & Lim (2003) demonstrates that a vibration frequency of 30Hz produced the greatest vastus lateralis muscle activity, and therefore this may contribute to an increase in oxygen uptake.

Whole body vibration (WBV) has been studied in greater detail than vibratory massage, and has shown increases in metabolic rate when the frequency was applied at 26Hz (Rittweger *et al.*, 2002). However, due to the nature of the WBV protocol it is difficult to compare the results with the present study because mechanical vibration massage was only applied to the limbs when the subject was lying on a therapy couch. One possible reason for the increased oxygen uptake during WBV (Rittweger *et al.*, 2002) would be due to the subjects being vibrated in a standing position. In this position, the subjects are supporting their entire body weight, and as such, the posture as well as the vibration would have necessitated a proprioceptive response causing reactive muscular contractions, and this may have contributed to the increase in oxygen uptake. In the present study, subjects lay on a therapy couch, with their weight supported, and the mechanical vibratory massage was only applied to one area of the legs for specified time periods.

Despite not affecting oxygen uptake and carbon dioxide output, the massage conditions did have an effect on respiration. Although these alterations in the continuants of respiration were statistically significant, they may however be physiological inconsequential as the alterations were so small; a conclusion which was also drawn by Wang & Keck (2004) following the administration of a 20min foot and hand massage, despite respiratory rate decreasing significantly by 1.6cycles · min^{-1} (p=0.004) . In this present investigation, there was no significant difference in ventilation *per se*; however, there was a significant difference in the contributors of ventilation. The results indicated a significant decrease in respiratory rate (8.1% (MM) and 6.8% (VM)) compared to baseline. Furthermore, there was a significant difference between the massage conditions and Rest. These results are in agreement with Barr & Taslitz (1970), Hayes & Cox (1999), and Okvat, Oz, Ting & Namerow (2002). In addition to this decrease in RR, there was a concomitant increase in tidal volume (7.7% (MM) and 5.1% (VM)); but as most research which reports RR does not include V_T or PV data, it is not possible to compare directly. The only study which has reported this data was Doering *et al.*, (1999) who investigated the effects of manual vibratory massage on pulmonary function. They reported a significant 10.1% decrease in respiratory rate and a significant 19.9% increase in tidal volume with no significant alteration in pulmonary ventilation. This latter finding is consistent with the results of this present study.

In common with this present investigation, a previous study by Hayes & Cox (1999) investigated the effects of massage on the lower parts of the leg and foot. They reported a significant decrease in RR from 23.04±6.22 to 21.25±5.72cycles · min^{-1} following a 5min procedure. They also reported a concomitant decrease in HR and SBP during treatment; however, at five minutes post treatment the HR and BP had returned to normal, but the RR continued to fall. The study by Hayes & Cox (1999) did not have a control rest group, and therefore it is not possible to ascertain whether the relaxation effect was as a product of the massage, or merely lying in a prone position. In this respect Boone, Tanner & Radosevich (2001) suggest that merely laying in a relaxed position on a therapy couch does not have any relaxation effect, when compared to massage.

Other studies which have reported decreases in respiratory rate have massaged the back, neck and shoulders (Barr & Taslitz, 1970; Hayes & Cox, 1999; and Okvat, Oz, Ting & Namerow, 2002). Understandably, with a back massage in a supine position, the mere action of the massage could in some way affect or control breathing by the rhythmic massage action. This has been proposed previously by Barr & Taslitz (1970) who observed through respiratory tracing, that hand pressure on the back caused a decrease in RR, and *vice versa.*

The only other research reporting pulmonary ventilation data whilst investigating leg massage did not report respiratory rate, but did include pulmonary function data, which did not significantly increase with massage (Gupta, Goswami, Sudhukhan & Mathur, 1995). In this present study, PV was maintained by a decrease in RR and an increase in tidal volume.

Respiration is now being investigated and reported more frequently in the literature, with most research suggesting that the relaxation response would decrease respiratory rate; however, the mechanism underlying any changes caused by massage has yet to be elucidated. Although massage will have no effect on the motor drives to ventilation (e.g. dorsal and ventral respiratory group (Ward, 2004)), it may have an effect by altering lung space through vagal modulation, or higher brain centers influence on the pneumotaxic, both of which would have an effect on tidal volume.

During this investigation the HRV data suggest that both massage conditions have a positive relaxation effect by increasing parasympathetic drive to the heart. Therefore, this indicates that there may be a vagal effect on smooth muscle. The increased vagal activity caused by the massage would result in the excitation of cholinergic receptors of bronchiole smooth muscle by acetylcholine, which results in bronchoconstriction, resulting in a decrease in air flow to the alveoli, which may result in a reactive increase in tidal volume. Therefore in order to maintain the partial pressure of CO_2 at its innate setpoint of 40mmHg (Tortora, 2005), respiratory rate would decrease.

Although it was beyond the scope of the study to investigate the direct effects of massage on the CNS and brain, it is postulated that the inhibition of the apneustic and pneumotaxic centers by the hypothalamus and limbic system, may cause a decrease in respiratory rate, and increase in tidal volume (Marieb, 2006), and *visa versa.*

In conclusion, despite a decrease in respiratory rate, there was a concomitant increase in tidal volume, thus maintaining a stable pulmonary ventilation. Furthermore, massage (manual or vibratory) did not have any significant effect on oxygen uptake or carbon dioxide output, even though they were higher than the values for Rest.

3.31 The effect of leg massage on skin and body temperature

Manual or vibratory massage were equally as effective at significantly elevating skin and aural temperature in the present studies. During Investigation 1 the leg skin temperature (Leg_{Temp}) for MM increased by 6.4% and VM by 8.0% following 30mins leg massage; and during Investigation 2 Leg_{Temp} increased by 4.8% for MM and by 7.0% for VM. This response also increased body is confirmed by the increase in $Aural_{Temp}$ by 0.4°C and 0.8°C for manual and vibratory massage respectively. The underlying mechanism behind this increase in aural temperature is unclear; however, as there is an evident increase in leg skin temperature, and a reported increase in muscle temperature caused by the friction of massage (presented by Drust *et al.*, 2003), this may therefore increase blood temperature, thus causing a concomitant response on core temperature. To date this response has yet to be elucidated.

3.32 The effect of leg massage on limb blood flow

Compression through repeated effleurage and petrissage results in retrograde arterial flow, and a consequential pressure surge during release (Shoemaker, Tiddus & Mader, 1997). In addition, local heating has been shown to increase venous compliance and therefore venous capacitance (Folokow & Neil, 1971; Rowell, 1998; and Schmitt *et al.*, 2002).

Despite an increase in limb skin temperature it is apparent from the plethysmograph data that massage (manual or vibratory) did not affect limb blood flow following a period of Rest. The findings support the work of Shoemaker, Tiidus & Mader (1997) and Hinds *et al.*, (2004) who both found no change in quadriceps blood flow following 5mins and 12mins of massage respectively, regardless of the type of massage administered. Both aforementioned studies concluded that manual massage did not induce significant changes in arterial and venous flow, or total muscle blood flow compared to Rest. However, the studies did observe a slightly elevated increase in blood flow compared to baseline, but neither study found that this was statistically significant.

In the present investigation, blood flow measurements were taken at baseline, on completion of the massage treatment, and at the end of the additional 10min rest period. When subjects were massaged, there was no significant difference between the control Rest group and massage conditions at any point; or between the untreated control and treated legs, indicating that massage did not affect leg blood flow.

Venous occlusion plethysmography has been used to measure limb blood flow in humans for nearly 100 years (Hewlett & Zwaluwenburg, 1909). The method by which plethysmography works is very simple. When compression is applied to the limb, venous drainage is interrupted but arterial flow is not. This is followed by an initial linear increase in limb blood volume over time until the limb reaches maximum venous capacitance (Hiatt *et al.*, 1989; and Wilkinson & Webb, 2001). At this point, there will be a slight concomitant increase in limb circumference (Schmitt, Blackman, Middleton, Cockcroft & Frenneaux, 2002; and Yang & Sacco, 2002).

The SciMed plethysmograph was used during the present investigation for the indirect estimation of blood flow. The method has been shown to be a valid and reliable method for estimating any increases in limb blood flow (Yang & Sacco, 2002), with the results comparing favourably to Doppler ultrasound (Tschakovsky, Shoemaker & Hughson, 1995). Despite the method being minimally invasive and simple to administer, its use has been criticised by other research in the field of massage, for several reasons (Hiatt *et al.*, 1989; Shoemaker, Tiddus & Mader, 1997; Hinds *et al.*, 2004; Chuah, Woolfson, Pullan & Lewis, 2004; and Weerapong, Hume & Kolt, 2005):-

1. blood flow cannot be expressed quantitively as the plethysmograph trace cannot be calibrated
2. the method is very sensitive to movement, causing movement artefact on the trace
3. it underestimates blood flow, as it may reduce arterial inflow due to the inflated cuff
4. limb blood flow cannot be measured during massage

5. the method cannot differentiate between muscle and skin blood flow.

During the present investigations, it was only possible to measure limb blood flow with the plethysmograph on completion of the massage treatment, as the placement of the cuffs on the leg would have limited the skin surface area to massage, and presumably prove detrimental to the effectiveness of the massage. Also, the movement of the hands on the limb would have caused considerable motion artefact on the trace (Fronek, Goldman & Fronek, 1998; Wilkinson & Webb, 2001; and Yang & Sacco, 2002). Data from Shoemaker, Tiidus & Madder (1997) suggests that the act of massage would have a transient effect on blood flow, which would normalise rapidly and have no residual effect; and therefore any measurement with a plethysmograph on completion of massage would need to be instantaneous. This was the case in the present study where the measurement of blood flow was taken immediately on completion of the massage.

The aim of this present investigation was to validate and extend the work of Bell (1964) and Wyper & McNiven (1976), by incorporating more subjects and using reliable and valid methodologies. Both aforementioned studies massaged the calf for 10mins, and both noted large increases in blood flow for one of their subjects. Bell (1964) observed a doubling of limb blood flow using plethysmography; and Wyper & McNiven (1976) observed an increase of 400% using ^{133}Xe tracer injection.

Hinds *et al.*, (2004) used a Doppler flowmeter and also reported that one of their subjects had a substantial increase in blood flow following massage, compared to the other subjects in the study. This again may have been due to the intra-subject variability; however, there is no definite rationale why this would occur (Saltin, Rädegran, Koskolou & Roach, 1998). Inter-subject variability of this magnitude was not observed in this present investigation (deemed for the standard deviation), during manual or vibratory massage.

3.33 The effect of leg massage on perception of feeling

In addition to the positive physiological effects seen during the massage conditions, the results for perception of feeling indicated that manual and vibratory massage also had a significantly greater psychological effect at the end of treatment than passive

Rest. During the two investigations, subjects perceived that they felt more relaxed during the massage conditions when compared to Rest. These findings may have resulted from a decrease in stress, which is possibly mediated by an increase in parasympathetic activity and reduction in sympathetic activity, or *visa versa.*

The psychological and physiological responses of massage is speculated to be a integrated and reciprocal process. The initial response would be mediated, in the first instance, by stimulation of the mechano and proprioceptors. The primary afferent neurons, as a consequence of the deformation or stretch of these fibres, would synapse in the dorsal column nuclei and ascend as second order neurons to the diencephalon (Marieb, 2006). The thalamus would relay to the hypothalamus, which would perceive the process of as massage relaxing stimuli. Consequently, the hypothalamus would regulate and decrease circulating adrenaline and noradrenaline, and modulate the function of the autonomic nervous system (↓ sympathetic; ↑ parasympathetic drive) (Ganong, 2003). This response would decrease heart rate through increased heart rate variability, decrease blood pressure though vasodilatation, alter respiration; and ultimately decrease anxiety, promote relaxation, and enhance perception of feeling. From this point onwards, this psychological and physiological alteration may become reciprocal process as the thalamus and hypothalamus maintain the body in a relaxed state. This area of research warrants further investigation, as it may reveal a greater understanding of the psychophysiological effects of massage.

From the literature, it appears that there are two possible mechanisms, either through alteration in brain activity or through neural or circulating biochemical markers. First, in respect of the effect of manual massage altering brain activity Diego, Field, Sanders & Hernańdeź-Reif (2004) showed an alteration in electroencephalographic activity following manual and vibratory massage towards relaxation. Upon completion of a 10mins back, shoulder and neck massage there was a significant increase in delta activity, and decrease in alpha and beta activity. The decrease in alpha and beta waves are indicative of a decrease in anxiety and arousal; and increase in delta waves is indicative of increased relaxation and commonly seen during deep sleep (Tatum, Husain, Benbadis & Kaplan, 2007). Along with this response, there was a change in frontal EEG asymmetry shifting from right asymmetry towards left frontal asymmetry, which is indicative of positive mood enhancement (Davidson, 2000; and Habel, Klein, Kellermann, Shah & Schneider, 2005). The results confirm earlier work by Jones & Field (1999) who reported the same effect in depressed adolescents using only manual massage. Jones & Field (1999) and Diego, Field, Sanders & Hernandez-Reif (2004) correlated this EEG measured response with self reported enhancement of relaxation and mood, and decrease in anxiety and stress. The concluding remarks of the Diego *et al.*, (2004) study reported that both MM and VM had a positive effect on brain activity and perception of mood, but the response for VM was less pronounced than that of MM. The author's did not speculate why the reason for the VM response was not as pronounced as MM; however it may be due to touch interaction between the therapist and subject (during MM), which has been shown to decrease anxiety, stress, heart rate and mean blood pressure, thus indicating a parasympathetic effect (Wendler, 2003 and McCaffrey & Taylor, 2005).

Furthermore, brain blood flow has also been used as an indicator of brain activity. Ouchi *et al.*, (2006) reported that following a 24min manual massage of the neck, shoulders and back that there was an increase in cerebral blood flow in the awareness related posterior brain region, which correlated with a decrease in heart rate, stress, anxiety and enhancement in mood. The authors conclude that the increase in mood maybe associated with the involvement of the forebrain-amygdala system in mediating activities in the autonomic nervous system in the presence of the calming effect of manual massage. In conclusion, it appears from the research available that massage (manual and vibratory) have an effect on brain activity, which indicate a positive psychological response.

Secondly, manual massage has also been associated with an alteration in biochemical markers in general circulation (cortisol), in the brain (serotonin), central nervous system (dopamine) and peripheral nervous system (β-endorphin) (Marieb, 2006); which may ultimately result in positive mood enhancement and improved mood and perception of feeling through alterations within the hypothalamus.

Cortisol (an indirect measure of parasympathetic activity (Field, Hernandez-Reif, Diego, Schanberg & Kuhn, 2005)) has been shown to decrease following a bout of manual massage in healthy dance students (Leivadi *et al.*, 1999), pregnant women

(Field, *et al*., 1999), migraine sufferers (Hernandez-Reif, Dieter, Field, Swerdlow & Diego, 1998), and cancer patients undergoing chemotherapy (Stringer, Swindell & Dennis, 2008). In all the studies, the decrease in cortisol correlated with an associate enhancement in perceived mood and wellbeing. Furthermore, manual massage has been shown to increase serotonin and dopamine, central nervous system neurotransmitters which are associated with mood enhancement (Young, 2007). Field *et al*., (2004) observed a decrease in cortisol (↓23%), and increase in serotonin (↑25%) and dopamine (↑23%) following a 20min massage of 84 depressed pregnant women; once again there was an associated enhancement in perceived mood.

In respect of β-endorphin, Kaada & Torsteinbø (1989) reported that following a 30min manual massage plasma β-endorphin increased significantly by 16% compared to control rest. They concluded that the increase β-endorphin linked to an increase in the feeling of warmth, relaxation and well-being, and possibly a decrease in pain.

Whilst there is little evidence in the literature of the effect of vibratory massage on biochemical markers, whole body vibration (WBV) has been investigated in this respect. Erskine, Smillie, Leiper, Ball & Cardinale (2007) report a decrease in serum cortisol following 10mins of vibration at 30Hz. Conversely, Cardinale, Soiza, Leiper, Gibson & Primrose (2008) observed that WBV increased cortisol. A comparison of WBV with the present VM protocol may not be appropriate, there is therefore insufficient evidence to enable a precise conclusion as to the whether vibratory massage would have a similar effect to manual massage on biochemical markers and mood enhancement. However, the evidence that manual massage may have a greater effect on these biochemical markers may come from the perception of feeling scale (in the present study) where subjects consistently reported a greater effect of MM.

CONCLUSIONS

3.34 Conclusions

In conclusion, following a 10min calf massage and 30min leg massage, MM and VM had no effect at increasing limb blood flow, and either oxygen uptake or carbon dioxide output above that of passive Rest. These finding are in agreement with other investigations that have failed to demonstrate a significant elevation in blood flow or metabolic rate by massage. However, leg massage did have an effect on breathing frequency, which decreased during treatment, a response which has been reported previously, but the degree of change of this response may be too small to be physiologically or clinically significant.

The data from the current investigation also suggests that both massage conditions are equally effective at decreasing heart rate, systolic blood pressure and rate pressure product by decreasing sympathetic and increasing parasympathetic drive to the heart, which is in agreement with Delaney, Leong, Watkins & Brodie (2002). Furthermore, massage enhanced perception of feeling, possibly due to psychological relaxation.

CHAPTER 4

The effect of single whole leg massage following a bout of aerobic cycling exercise

(Investigation 3)

INTRODUCTION

On massage Buckle (2007) said "I found that if I did at least three strokes of the same type, the patient's pulse and breathing slowed and their blood pressure came down.......at first touch, the body registers surprise; on the second it recognises the feeling; and by the third it is reassured that this is something it can cope with" (Lantin, 2007)

4.1 Overview

At rest the administration of massage is said to bring about an alteration in cardiac autonomic activity, causing an increase in parasympathetic activity; furthermore it has been shown to elicit a psychological relaxation (Delaney, Leong, Watkins & Brodie, 2002). However, there is currently no research available which has investigated the effects of massage (massage or vibratory) on cardiac autonomic activity after a bout of exercise.

Another mechanism by which massage is said to elicit a response is by augmenting limb blood haemodynamics. At present, there is paucity of research reporting an effect of manual massage on limb blood flow post exercise. Furthermore, there is no research data available to confirm the effect of vibratory massage on limb blood flow, despite the manufacturers claims that mechanical vibratory massage increases limb blood flow.

AIMS

4.2 Aims

The aim of Investigation 3 (massage administered following exercise) was to elucidate the effects of massage (manual or vibratory) following a bout of aerobic exercise. During recovery, the right leg was massaged, with the left leg acting as a control, which ensured that there was a between limbs comparison, as well as an inter-subject comparison for the limb blood flow measurements. Other measurements taken in the study were cardiac autonomic activity, blood pressure, body temperature, calf circumference, blood lactate concentration and perception of feeling.

An additional period of 10mins rest was included at the end of the 20min massage period. This was included to gauge whether any effects of massage would persist throughout the 10min period, or whether the relaxation effects are merely transient, and an indirect result of the massage administration.

SPECIFIC MATERIALS AND METHODS (Investigation 3)

4.3 Subjects

The six male subjects (Table 4.1) participating in the study were physically active and free from illness or injury (mean±SD: age 21.5±3.4yrs, weight 75.7±8.3kg, height 177.3±5.1cm and $VO_{2\ max}$ 50.1±4.5ml O_2 kg^{-1} min^{-1}). Each subject completed the three recovery modes in a different order (Table 4.2) to minimise bias. There was a minimum of three days between each test, to allow sufficient recovery.

Table 4.1 Age, height, weight, peak heart rate, $VO_{2\ max}$ and main participation sport of the 6 male subjects participating in Investigation 3.

Subject No.	Age	Height	Weight	Peak HR	$VO_{2\ max}$	Main sport
1	20	180	85.4	189	52.1	Rugby
2	24	180	80.2	181	45.4	Cycling
3	27	172	65	190	46.2	Hockey
4	21	170	66.7	171	52.2	Cycling
5	19	179	75.6	187	47.5	Hockey
6	18	183	81.5	180	57.1	Swimming

Table 4.2 Randomly assigned recovery methods for each subject during Investigation 3.

Subject	1	2	3	4	5	6
R	1	2	3	1	3	1
MM	2	3	1	3	2	2
VM	3	1	2	2	1	3

Subjects were requested to refrain from any form of heavy exercise 48hrs before each testing session. They were also requested to refrain from consuming alcohol or caffeinated drinks for 24hrs prior to the test, and were tested in a 1hr postprandial condition. All tests were performed in an ambient room temperature of between 21 - 24°C.

4.4 Preliminary measurements

Maximal oxygen uptake and maximum heart rate was estimated a week prior to the experiment (detailed in Chapter 2). The results of the test were used to set the work rate for the cycling exercise protocol.

4.5 Exercise Test

The 20min cycling protocol was conducted on a calibrated Monark 818*E* weight loaded cycle ergometer. Subjects were required to warm up for 5mins at 80rpm, and gradually increase the resistance until they achieved a HR of 80%HR_{max} within the 5^{th}min, at this point the 20min cycling protocol commenced. They were required to maintain a cadence of 80rpm, and the experimenter altered the resistance in order to maintain their target heart rate.

4.6 Recovery Protocols

4.6.1 Manual leg massage (MM): The 20min prone/supine leg massage was administered to the right leg. Subjects lay in a prone position, and the posterior aspect of the leg was massaged for 10mins; followed by massage to the anterior aspect of the leg in a supine position for the same time period. The general sequence of massage is detailed in Table 4.3. Subjects were requested to remain still and quiet throughout.

4.6.2 Vibratory leg massage (VM): The vibratory leg massage was administered using the U-shaped sponge (app. 230) at 30Hz to simulate effleurage, and using the 4-ball adaptor (app. 216) at 60Hz to simulate petrissage.

Table 4.3 General sequence of the 20min calf massage (manual and vibration) for prone then supine positions during Investigation 3.

Prone	Time (min)	Supine	Time (min)
Superficial effleurage of whole leg	0.5	Superficial effleurage of whole leg	0.5
Superficial effleurage of hamstrings	0.5	Superficial effleurage of quadriceps	0.5
Deep effleurage of hamstrings	1	Deep effleurage of quadriceps	1
Kneading of hamstrings	0.5	Kneading of quadriceps	0.5
Superficial effleurage of whole leg	0.5	Superficial effleurage of whole leg	0.5
Deep effleurage of calf	0.5	Deep effleurage of tibialis anterior	0.5
Deep effleurage of whole leg	1	Deep effleurage of whole leg	1
Superficial effleurage of whole leg	0.5	Superficial effleurage of whole leg	0.5

4.6.3 Rest (R): Subjects were required to lay in a prone position for 10mins, and then in a supine position for a further 10mins.

4.7 Data collection

The protocols for rating of perceived exertion, heart rate, heart rate variability, blood pressure, rate pressure product, body temperature, limb blood flow, and perception of feeling data collection are explained in Chapter 2. The method for estimating changes in calf circumference is detailed in Chapter 3.

4.8 Timeline of measurements

Baseline measurements were taken with the subject lying in a supine position. Prior to the measurements, subjects rested for 10mins in a supine position in a quite room at an ambient temperature of 21 - 24°C. Table 4.4 illustrates which measurements were taken, and when.

Table 4.4 Measurements taken at each time point during Investigation 3.

		HR	HRV	BP	Temp	Limb flow	Calf circ.	BLa	PoF
	Baseline	✓	✓	✓	✓	✓	✓	✓	✓
Exercise	**During CE**	✓		✓	✓			✓	✓
	End of CE	✓	✓	✓	✓	✓	✓	✓	✓
Massage	**3mins post**	✓		✓	✓			✓	✓
	5mins post	✓		✓	✓			✓	✓
	10mins post	✓		✓	✓			✓	✓
	20mins post	✓	✓	✓	✓	✓	✓	✓	✓
	End of additional 10mins rest	✓	✓	✓	✓	✓	✓	✓	✓

4.9 Statistical Analysis

Parametric data are presented as Mean ± Standard deviation (SD). Prior to testing the experimental hypotheses, Shapiro-Wilks normality test and Levene's homogeneity of variance test were performed on all data; these checks revealed satisfactory outcomes for all variables apart from the heart rate variability and limb blood flow data, which was not normally distributed. Repeated measures ANOVA and *post hoc* paired samples *t*-tests were performed to compare effects between conditions. Paired *t*-test analysis was also used to compare post treatment to baseline. Non-parametric data (perception of feeling) are presented as Median ± InterQuartile Range (IQR). The perception of feeling heart rate variability and limb blood flow data were analysed with Friedman's test, and *post hoc* with Wilcoxon's signed-rank test in order to compare effects between conditions. For correlation analysis, Pearson's bivariate correlation coefficient analysis was calculated. The level of significance was taken as $p<0.05$.

RESULTS

4.10 Results of the aerobic cycling exercise bout (80% HR_{max})

Subjects were required to cycle at a constant cadence of 80rpm, and requested to alter the resistance to achieve the target heart rate of 80% HR_{max}. During the 20min exercise bout mean power output was 163.2±11.8Watts and subjects registered a Rating of Perceived Exertion of 13 (IQR 12, 14) (Somewhat Hard).

4.11 The effect of massage on heart rate

Heart rate is presented as the one minute average for each time point. Baseline HR was 63.7±8.3bpm; this increased to 146.3±2.0bpm (80.1±3.6%HR_{max} or 71.4±4.7%VO_{2max}) during aerobic exercise bout (Figure 4.1). On completion of the CE, HR began to decrease towards the baseline level. Heart rate for MM was significantly lower than R for the last 10mins of the recovery period (p=0.011), and throughout the additional 10mins rest period (p=0.032). Similarly, the HR for VM was significantly lower than R for the last 10mins of the recovery mode (p=0.041), however there was no difference during the additional 10mins rest period (p=0.33). There was no significant difference between MM and VM.

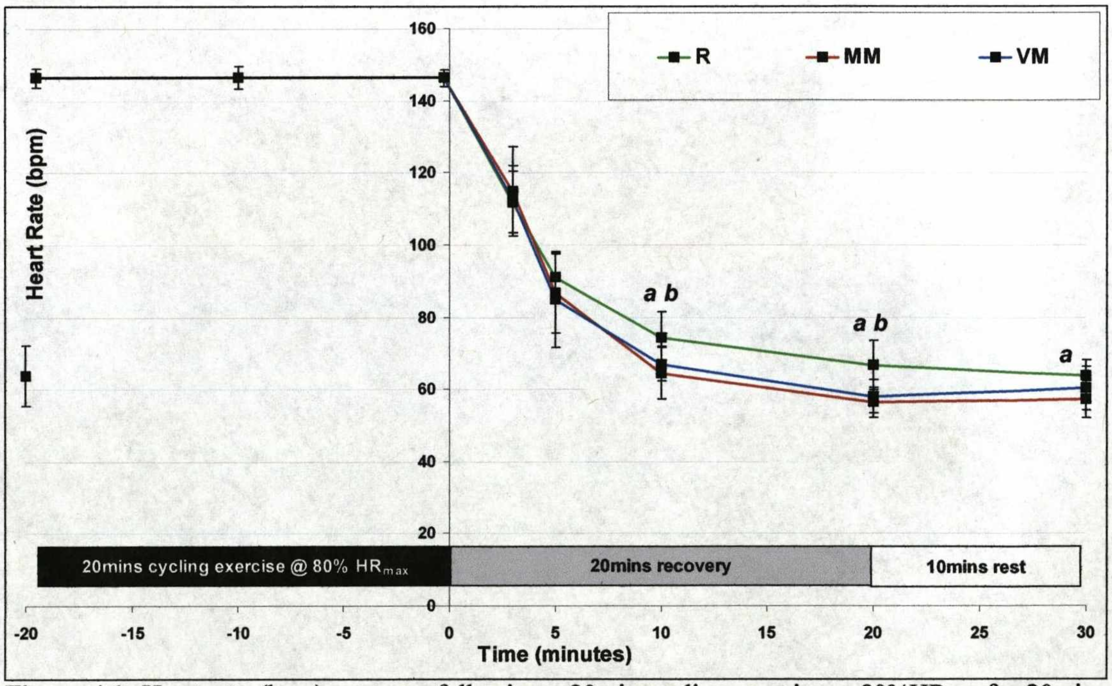


Figure 4.1 Heart rate (bpm) response following a 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = MM *vs* R and ***b*** = VM vs R.

4.12 The effect of massage on cardiac autonomic activity

There was a significant decrease in the indicators of sympathetic heart control for MM compared to R at the end of the 20min recovery (Table 4.5) (LFnorm p=0.023; and LF:HFratio p=0.011). This effect continued to the end of the additional 10min recovery period (LFnorm p=0.033; and LF:HFratio p=0.036). A significant decrease was also seen for VM compared to R at the end of the 20min recovery (LFnorm p=0.041; and LF:HFratio p=0.044). No significant difference was seen at the end of the additional 10min recovery period (LFnorm p=0.29; and LF:HFratio p=0.41). There was no significant difference between MM and VM.

There was a significant increase between the indicators of parasympathetic heart control for MM compared to R at the end of the 20min recovery period (RMSSD p=0.021; pNN50 p=0.014; and HFnorm p=0.022), which continued to the end of the additional 10min recovery period (RMSSD p=0.041; pNN50 p=0.044; and HFnorm p=0.032). A significant difference was also seen between R and VM at the end of the 20min recovery (LFnorm p=0.043; LF:HFratio p=0.046; and HFnorm p=0.041). No difference was seen at the end of the additional 10min recovery period (LFnorm p=0.29; LF:HFratio p=0.41; and HFnorm p=0.33). There was no significant difference between MM and VM.

In summary, MM and VM are equally effective at decreasing cardiac sympathetic and increasing parasympathetic activity during recovery from a bout of cycling exercise.

Table 4.5 Heart Rate Variability (time and frequency domain) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = MM *vs* R, and ***b*** = VM *vs* R. **Parasympathetic**, **Sympathetic** and **Sympathovagal** indicators.

	Baseline	Rest After 20mins recovery	Manual Massage After 20mins recovery		Vibratory Massage After 20mins recovery	
HR	63.7 ± 8.3	66.6 ± 6.9	56.2 ± 4.2	***a***	57.8 ± 4.7	***b***
LF norm	69.6 ± 14.7	73.3 ± 9.7	61.2 ± 9.0	***a***	63.5 ± 10.2	***b***
LF:HF Ratio	2.48 ± 1.4	3.01 ± 1.4	1.71 ± 0.7	***a***	1.91 ± 0.8	***b***
HF norm	30.4 ± 14.7	26.7 ± 9.7	38.8 ± 9.0	***a***	36.5 ± 10.2	***b***
RMSSD	55.5 ± 14.4	48.1 ± 18.4	64.2 ± 21.9	***a***	60.6 ± 32.8	***b***
pNN50	9.6 ± 3.7	6.9 ± 4.2	11.5 ± 6.0	***a***	10.8 ± 4.6	***b***
		Rest 10mins rest	**Manual Massage** 10mins rest		**Vibratory Massage** 10mins rest	
HR		64.2 ± 4.0	57.2 ± 5.1	***a***	60.2 ± 6.0	
LF norm		72.1 ± 4.7	63.4 ± 11.2	***a***	65.3 ± 10.0	
LF:HF Ratio		2.68 ± 0.7	1.95 ± 0.9	***a***	2.08 ± 0.8	
HF norm		27.9 ± 4.7	36.6 ± 11.2	***a***	34.7 ± 10.0	
RMSSD		50.2 ± 5.9	60.3 ± 20.9	***a***	53.2 ± 6.3	
pNN50		7.1 ± 2.2	9.1 ± 4.8	***a***	8.8 ± 2.1	

4.13 The effect of massage on blood pressure (systolic and diastolic)

4.13.1 Systolic blood pressure: Baseline SBP was 121.6±13.3mmHg, which increased to 141.1±8.7mmHg during the CE (p=0.00021). On completion of CE, there was a gradual decrease over time in all recovery methods, which corresponded with a similar trend in the heart rate i.e. the half time was approximately 4mins for both variables. There was no significant difference between the three recovery modes throughout the 20min recovery or the additional 10min rest period (Figure 4.2). Furthermore, by the end of the additional 10min recovery period SBP had returned to the baseline level (R (115.8±9.6mmHg), MM (117.9±10.5mmHg) and VM (116.1±11.3mmHg)).

4.13.2 Diastolic blood pressure: Baseline DBP was 68.5±7.5mmHg (Figure 4.2). There was an increase in DBP during CE (77.2±6.5mmHg) compared to baseline. No significant difference was seen between the three recovery conditions at any point. By the end of the 10mins additional recovery DBP had returned to baseline (R (69.9±4.7mmHg), MM (71.3±5.7mmHg) and VM (70.4±6.1mmHg)).

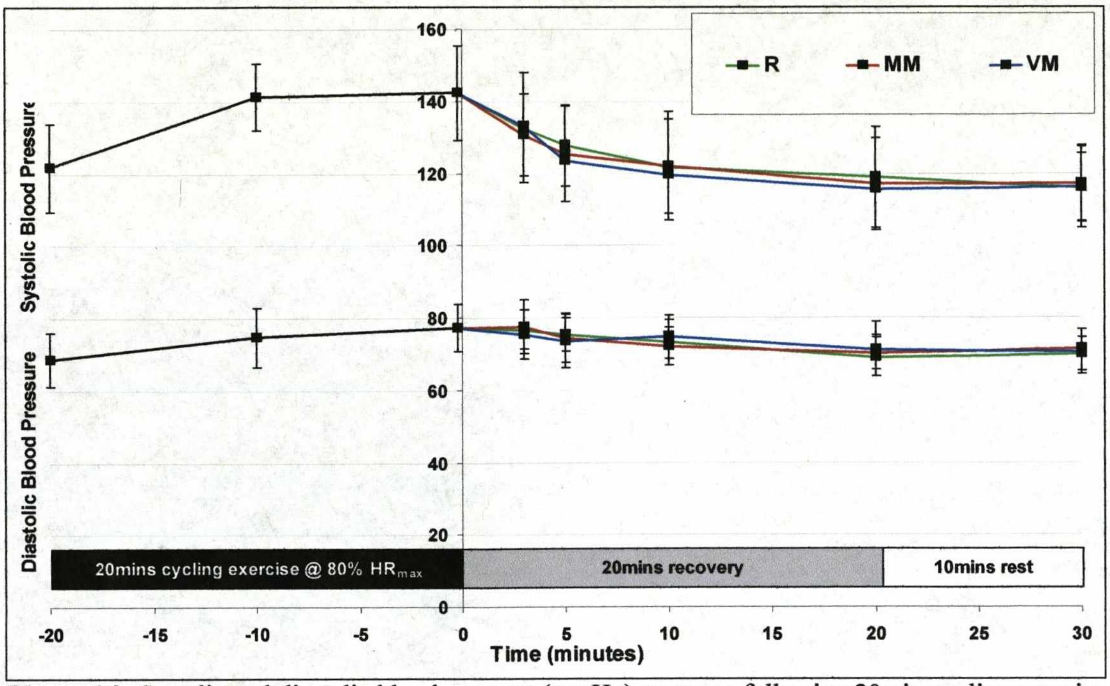


Figure 4.2 Systolic and diastolic blood pressure (mmHg) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6).

4.14 The effect of massage on rate pressure product

Baseline RPP was 7747±890units; this increased to 20650±1313units during CE (Figure 4.3). During recovery, RPP decreased for all recovery methods, and at the end of 20mins recovery the values for MM (6575±539units) (p=0.007) and VM (6685±452units) (p=0.005) were significantly lower than R (7914±764units). At the end of the 10mins additional rest the RPP for MM (6592±535units) and VM (6983±569units) remained significantly lower than R (7402±512units) (MM *vs* R p=0.0006; VM *vs* R p=0.0009). Furthermore, RPP at the end of 10mins additional rest for MM (p=0.017) and VM (p=0.021) were significantly lower than baseline. There results indicate that VM and MM were equally effective at decreasing cardiac power.

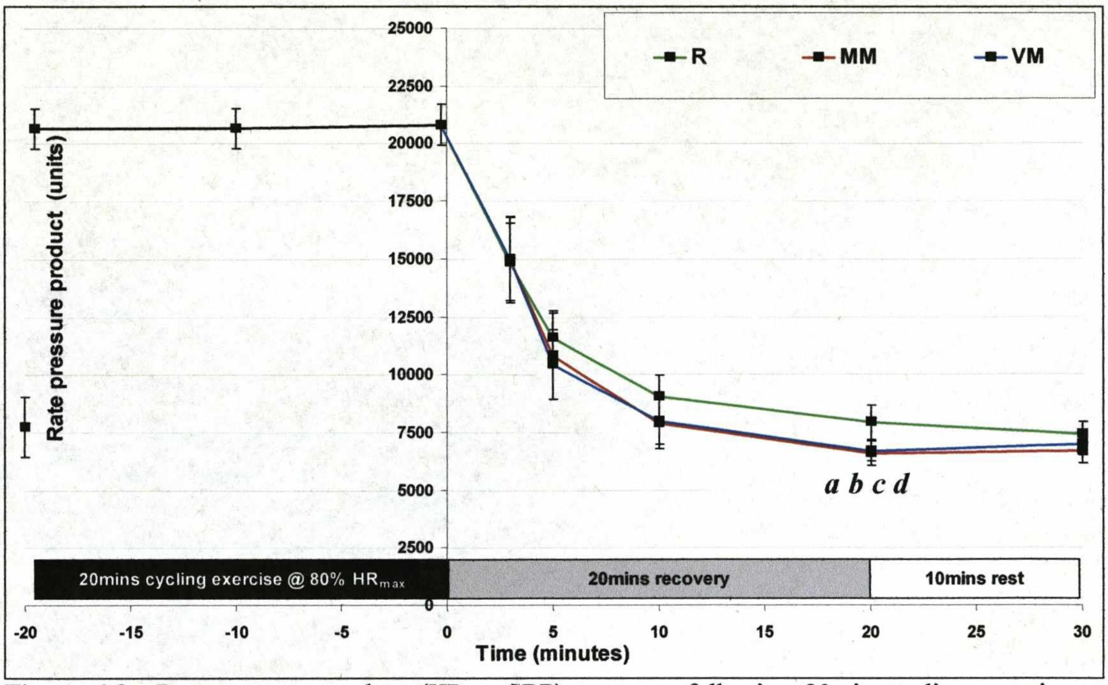


Figure 4.3 Rate pressure product (HR x SBP) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, ***c*** = MM *vs* Baseline, and ***d*** = VM *vs* Baseline.

4.15 Interaction between rate pressure product and heart rate/blood pressure

This results of the present investigation showed that RPP correlated highly with HR (r^2 = 0.8052), and not so highly with SBP (r^2 = 0.4164) (Figure 4.4). The data presented is pooled data from the three conditions for all time points.

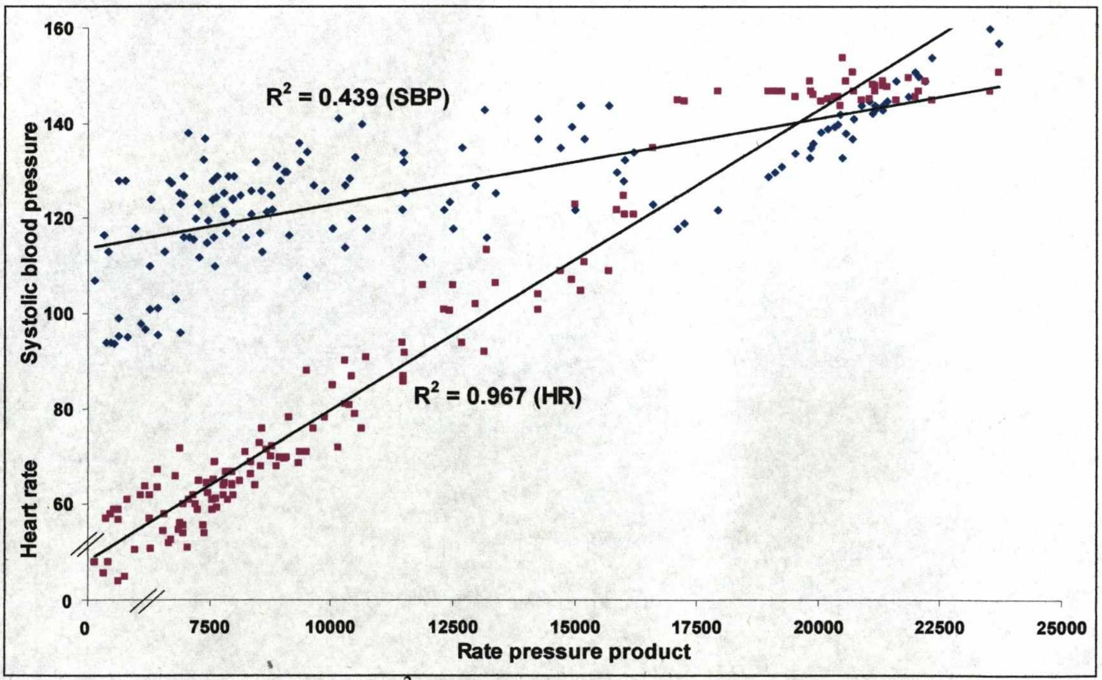


Figure 4.4 Correlation coefficient (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.

4.16 The effect of massage on leg and aural temperature

4.16.1 Leg Temperature Leg_{Temp}: From an initial Leg_{Temp} of 31.9±0.7°C at baseline; there was a significant increase to 33.2±0.5°C on completion of the CE (*p*=0.0040) (Figure 4.5). From this point onwards, temperature was measured from both the right leg (treated) and left leg (untreated) for the massage conditions. For the untreated leg (left), for all conditions, Leg_{Temp} remained elevated above baseline throughout the recovery period, and at the end of the 10mins additional rest period (R (32.4±0.6°C); MM (32.6±0.7°C) and VM (32.8±0.6°C)).

For the treated leg (right), skin temperature increased immediately upon administration of the manual or vibratory massage. At the end of the 20mins recovery period Leg_{Temp} was 36.2±0.4°C for MM and 36.9±0.64°C for VM; significantly higher than R (MM *p*=0.0002 and VM *p*=0.00001). At the end of the additional 10mins recovery period Leg_{Temp} had decreased somewhat, but remained significantly higher than R (MM (34.3±0.7°C; *p*=0.001) and VM (35.9±0.6°C; *p*=0.00034)). In addition, the Leg_{Temp} for VM was significantly higher than that for MM.

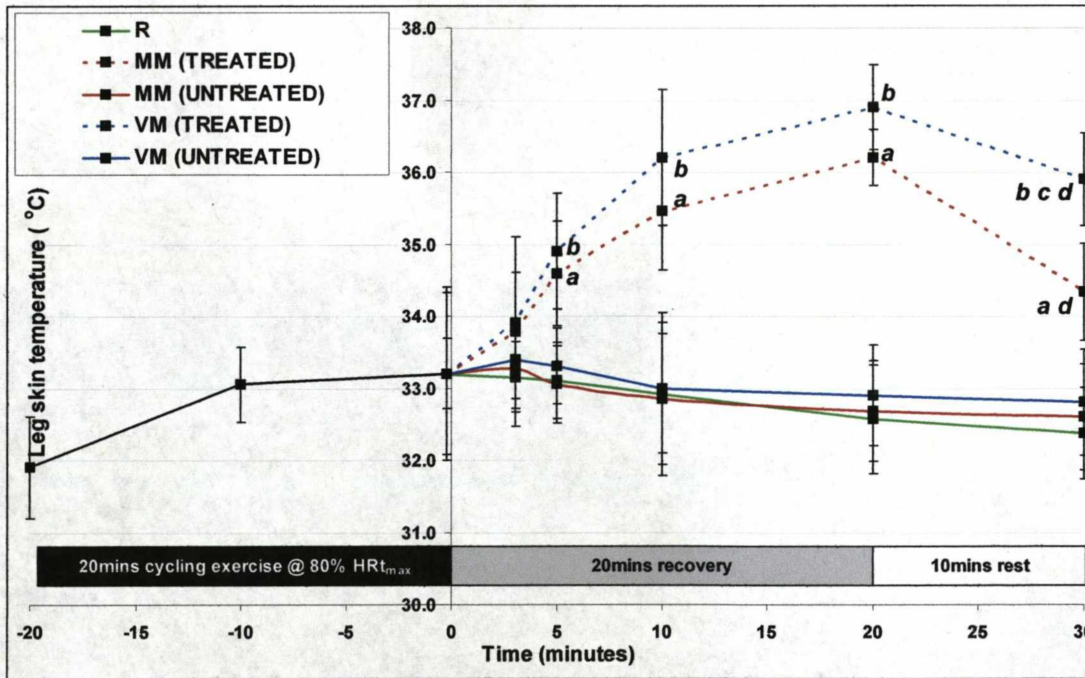


Figure 4.5 Leg skin temperature (°C) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (*n*=6). Significant differences ***a*** = MM *vs* R, ***b*** = VM *vs* R, ***c*** = MM *vs* VM, and ***d*** = 30mins post exercise *vs* baseline (all recovery modes).

4.16.2 Aural temperature ($Aural_{Temp}$): Baseline measurement of $Aural_{Temp}$ was 36.8±0.2°C (Figure 4.6). A small but significant increase was observed in $Aural_{Temp}$ on completion of the CE (p=0.002), which was followed by a gradual decrease throughout the course of recovery. $Aural_{Temp}$ remained elevated above the baseline until 3mins post CE for R (p=0.0103); and until 10mins post CE for MM (p=0.0021) and VM (p=0.0014). By the end of the additional 10mins recovery period $Aural_{Temp}$ had returned to baseline for all conditions (R (36.7±0.2°C), MM (36.8±0.2°C), VM (36.9±0.14°C)).

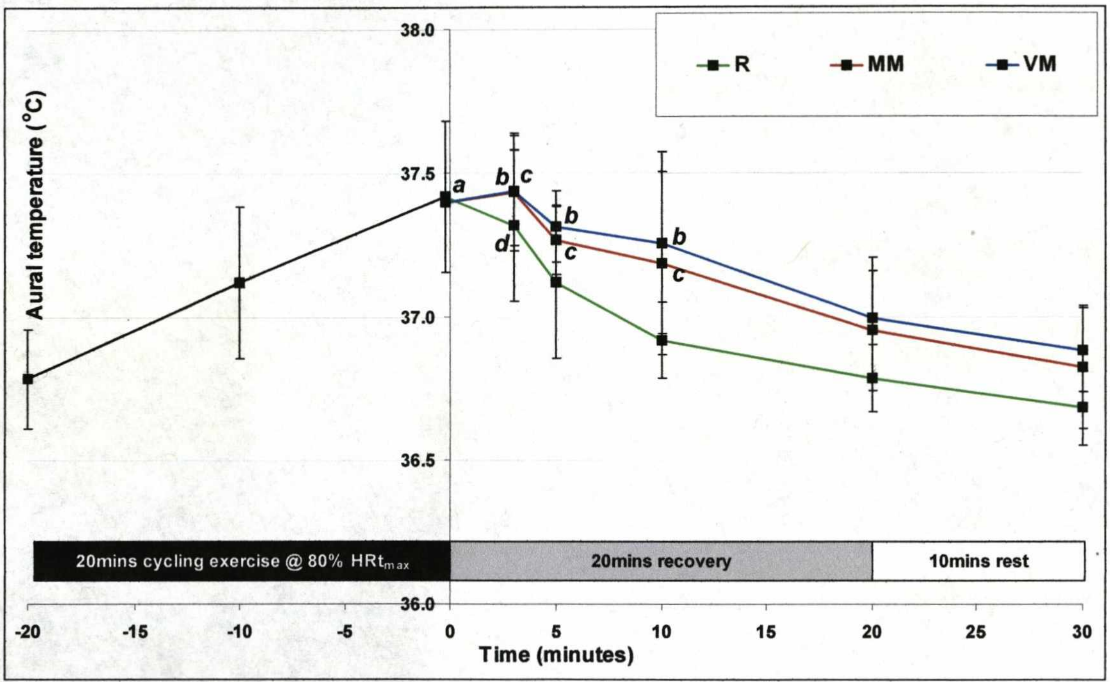


Figure 4.6 Aural temperature (°C) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6). Significant differences ***a*** = all conditions *vs* baseline, ***b*** = MM *vs* baseline, ***c*** = VM *vs* baseline and ***d*** = R *vs* baseline.

In summary, VM had the greater effect significantly increasing leg skin temperature above MM and R. This was also the case for aural temperature.

4.17 The effect of massage on the estimation of limb blood flow

Baseline estimation of limb blood flow was 0.21±0.9*AU*; this increased by 257.1% to 0.75±0.15*AU* at the end of the CE, and was significant higher than baseline (p<0.0001) (Table 4.6). LBF was measured immediately on completion of the 20mins recovery, and there was no significant difference was seen between the massage conditions and R; or between the post recovery values and baseline. There was a further decrease in LBF at the end of the additional 10mins recovery; again there were no significant differences.

Table 4.6 Estimation of limb blood flow response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (*n*=6). Significant differences (p<0.05) ***d*** = Baseline *vs* Post Exercise.

	R	**MM (treated)**	**MM (untreated)**	**VM (treated)**	**VM (untreated)**
Baseline	0.21±0.06*AU*				
Post exercise	0.75±0.16*AU* ***d***				
After 20mins recovery	0.3±0.09*AU*	0.31±0.08*AU*	0.31±0.07*AU*	0.31±0.07*AU*	0.31±0.06*AU*
End of 10mins rest	0.3±0.07*AU*	0.29±0.09*AU*	0.3±0.09*AU*	0.28±0.08*AU*	0.28±0.09*AU*

4.18 The effect of massage on calf circumference

Baseline CC was 38.0±0.8cm for the treated leg, and for the 37.7±0.9cm untreated control (Table 4.7). Followed by an increase to 38.2±1.1cm on completion of CE. At the end of the 20mins recovery period, CC remained elevated above baseline for all three recovery conditions; which was also the case at the end of the additional 10mins rest period. There was no significant difference between the treated and control leg for MM (p=0.32) or VM (p=0.26) at the end of recovery, or between the massage conditions and R.

Table 4.7 Calf circumference response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (*n*=6).

	R	**MM (treated)**	**MM (untreated)**	**VM (treated)**	**VM (untreated)**
Baseline	38.0±0.8cm (treated) 37.7±0.9cm (untreated)				
Post exercise	38.2±1.1cm				
After 20mins recovery	38.2±0.8cm	38.2±0.7cm	37.9±0.8 cm	38.1±0.4cm	37.8±0.4cm
End of 10mins rest	38.1±0.4cm	38.1±0.4cm	37.8±0.7 cm	38.0±0.6cm	37.7±0.9cm

4.19 The effect of massage on blood lactate concentration

The baseline level of BLa concentration was 1.16±0.3mmol · l^{-1} (Figure 4.7). This increased to 7.2±1.14mmol · l^{-1} during the 20min exercise period. BLa concentration for MM and VM were not significantly different from R throughout the recovery period. By the end of the 10min additional rest period the concentration of BLa was 1.47±0.3mmol · l^{-1} (R), 1.28±0.3mmol · l^{-1} (MM) and 1.2±0.3mmol · l^{-1} (VM), and were not significantly different from baseline.

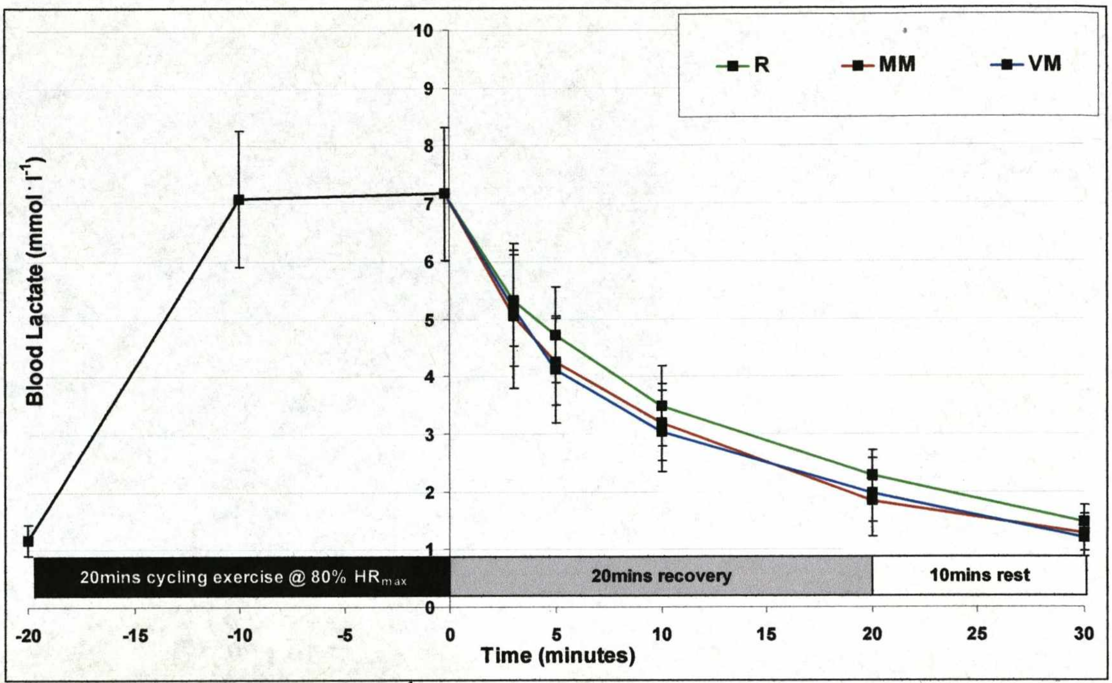


Figure 4.7 Blood lactate (mmol · l^{-1}) response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (n=6).

In summary, it is clear from the results that massage had no greater effect at decreasing blood lactate concentration than the Rest condition.

4.20 The effect of massage on perception of feeling

Perception of feeling decreased from 5.0 (IQR 4.25, 6.0) to 'Neutral' (-0.5 (IRQ -3, 1)) following CE (Figure 4.8). Feeling subsequently improved over the 20min recovery period at different rates. There was a significant difference between MM and R throughout (p=0.016), also between VM and R (p=0.017); and at the end of the additional 10mins rest subjects reported a PoF of 6 (IQR 5.25, 6) for MM and 5.5 (IQR 5.5, 6) for VM. In contrast to the massage conditions, the subjects during R reported a final PoF of 2.5 (IQR 2, 3) which was significantly different compared baseline (p=0.027). The results indicate that MM and VM were equally effective at enhancing PoF following a bout of aerobic exercise.

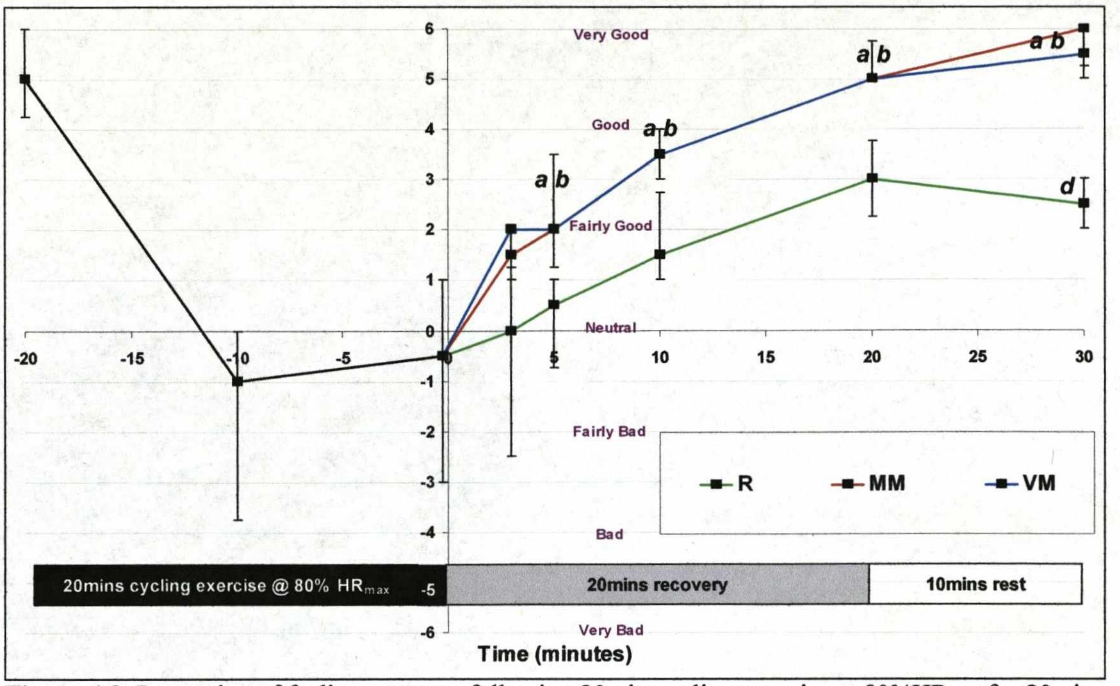


Figure 4.8 Perception of feeling response following 20min cycling exercise at 80%HR_{max} for 20mins Rest (R), Manual leg Massage (MM) and Vibratory leg Massage (VM) (*n*=6). Data presented as Median ± Interquartile range. Significant differences ***a*** = MM *vs* R, ***b*** = VM vs R and ***d*** = 30mins post exercise *vs* Baseline (R)

DISCUSSION

4.21 Purpose of the investigation

The purpose of this present investigation was to elucidate the effect of massage (manual or vibratory) on limb heamodynamics and cardiac autonomic activity post aerobic exercise. This is the first study to investigate the effect of manual or vibratory massage on sympathovagal balance following exercise. Furthermore, it is the only study to examine the effect of vibratory massage on limb blood flow, perception of feeling, and body temperature post exercise.

4.22 The effect of massage on cardiac autonomic activity

The change in sympathovagal balance caused by massage, and the consequent change in HR and RPP, was due to a combination of sympathetic withdrawal and vagal increase. The magnitude of response varied from the results in Chapter 3, with LF:HFratio decreasing 31.1% in this investigation, compared to 21.5% following a 30min leg massage (Investigation 1), and 38.2% following a 10min calf massage (Investigation 2). This indicated that leg massage, irrespective of duration or type, is effective at initiating a relaxation response, by increasing parasympathetic drive, and decreasing sympathetic drive, rate pressure product, and heart rate.

In conclusion, massage (manual or vibratory) was effective at decreasing cardiac sympathetic and increasing parasympathetic activity, thus reducing heart rate during recovery from a bout of cycling exercise. However, massage did not have a significant impact on systolic or diastolic pressure compared to Rest. The rate pressure product results indicate that in the absence of a measure of HRV, RPP could give a surrogate and reliable indication of sympathovagal balance.

4.23 The effect of massage on limb blood flow and body temperature

It is apparent from the plethysmography data that massage (manual or vibratory) did not affect limb blood flow during recovery from a period of 20min aerobic exercise. The findings support the work of Shoemaker, Tiidus & Mader (1997) and Hinds *et al.*, (2004) who both reported no change in quadriceps blood flow following 5mins and 12mins massage respectively, regardless of the type of massage administered.

In this present investigation, blood flow measurements were taken at baseline, immediately following exercise, on completion of the massage treatment, and at the end of the additional 10min rest period. The 20min aerobic exercise bout (80%HR_{max}) elevated limb blood flow by 693.8%. This effect persisted for all three recovery conditions throughout the 20min recovery, and additional 10min post recovery rest. However, the elevated flow was not significantly different from baseline.

Despite manual or vibratory massage not having a positive effect on limb blood flow or calf circumference, both massage methods significantly elevate leg skin temperature following exercise when compared to Rest. This response was seen for the duration of the 20min treatment and additional 10mins rest period. As expected, Leg_{Temp} increased during CE bout, 1.3°C above baseline levels. This increase during the 20min exercise bout was in all probability caused by a thermoregulatory response, dilating cutaneous circulation to increase body temperature, and dissipate heat (Rowell, 1988). This alteration is consistent with the increase in $Aural_{Temp}$ by 0.8°C during CE. During the massage, Leg_{Temp} was significantly higher than the R condition, and also the untreated leg. This effect was caused due to the friction of the effleurage and petrissage action on the skin, resulting in an increase in skin blood flow (4.3°C above baseline) in order to dissipate heat (Hinds *et al.*, 2004; and Weerapong, Hume & Koly, 2005). This is evident with a change in skin colour, where the treated area is redder than the surrounding skin. This effect was more pronounced for vibratory massage, as there was a greater increase in skin temp, 5°C above baseline levels, which was presumably caused by the greater friction of VM, and a greater increase in blood temeprature.

During MM, the rate of effleurage was approximately 0.5Hz; and petrissage, 2Hz. For VM, simulated effleurage was 30Hz, and petrissage was administered at 60Hz. Therefore, this greater increase in skin temperature seen during VM was as a direct result of the increased friction caused by the higher massage rate.

Drust *et al.*, (2003) and Hinds *et al.*, (2004) both suggest that this increase in skin temperature caused by massage correlates highly with increased skin blood flow, and both research studies conclude that an increase in skin blood flow, without a concomitant increase in total limb blood flow, would divert blood away from the muscle, which would be counterproductive for recovery from exercise.

4.24 The effect of massage on lactate clearance and limb circumference

Blood lactate concentration and limb circumference were measured in this present investigation as additional markers of recovery. Following the 20min aerobic exercise bout, it is evident that massage (either manual or vibratory) had no greater effect on lactate clearance than Rest. A more detailed discussion regarding the effect of massage and lactate clearance can be seen in Chapter 5.

Limb circumference was used as a measure of post exercise oedema. From the results, it is apparent the exercise bout did not cause significant post exercise oedema. A more detailed discussion regarding the effect of massage on post exercise oedema can be seen in Chapter 6.

4.25 The effect of massage on perception of feeling

In addition to the positive physiological effects seen during the massage conditions, the results for perception of feeling indicated that massage (manual and vibratory) also had a significantly greater psychological effect, during and after treatment, compared to Rest. The mechanisms by which massage may alter psychological perception are presented in section 3.33.

CONCLUSION

4.26 Conclusion

In conclusion, following a bout of 20mins aerobic exercise, MM and VM had no effect at maintaining an increased limb blood flow above that of passive Rest during recovery. These finding are in agreement with other investigations that have failed to demonstrate a significant elevation in blood flow by massage. However, the data from the current investigation indicated that MM and VM are equally effective at increasing limb skin temperature presumably due to the friction on the skin, this caused an increase in aural temperature, possible through an increase in blood temperature. The data from the current investigation also suggests that both massage conditions are equally effective at decreasing heart rate, systolic blood pressure and rate pressure product by decreasing sympathetic and increasing parasympathetic drive to the heart. Furthermore, massage enhanced perception of feeling, possibly due to psychological relaxation.

CHAPTER 5

The effect of continuous and combined leg massage on recovery from anaerobic exercise

(Investigation 4)

INTRODUCTION

"The object of massage is to disperse the effete matters (i.e. metabolites) formed in the muscles after exercise. It causes the effete matter to disperse and so remove fatigue"
Avicenna (980-1037)

5.1 Overview

The key to accelerated blood lactate concentration decrase from muscle following maximum intensity exercise may be due to the increased muscle blood flow. Consequently, if massage increases limb blood flow, it may also have an ability to decrease lactate cocentration, and consequently enhance short-term recovery (Dubrovsky, 1982; Drews *et al.*, 1990; Boone, Cooper & Thompson, 1991; Callaghan, 1993; and Goats, 1994b). However, the precise physiological changes that occur during massage to augment this proposed increase in flow are not well-defined (Rodenburg, Steenbeck, Schiereck & Bär, 1994 and Tiidus & Shoemaker, 1995).

Consequently, it is proposed that the administration of leg massage following a bout of maximal intensity exercise may have an enhanced response compared to Rest. It was assumed that blood lactate concentration is indicative of recovery from an intense exercise bout; for that reason the monitoring and reporting of blood lactate is of primary importance in this investigation, and therefore will be detailed first in the results of this chapter. Other variables monitored during recovery were heart rate, blood pressure, pulmonary ventilation, metabolic rate, body temperature, and perception of feeling; and it was expected that these physiological variables would confirm the efficacy of each recovery method.

For the investigation in this chapter, the Wingate Anaerobic Test (WAnT) was utilised as the short bout of intense exercise. A force of 7.5% body weight was chosen to yield high mechanical power, consequently induce fatigue, and increase blood lactate levels all within 30secs. Furthermore, the WAnT was selected in order to extend the research into recovery from single short duration anaerobic exercise. Previous researchers in the area have generally used multiple bouts of lower intensity exercise interspersed with short periods of massage (Gupta, Goswami, Sadhukhan & Mather, 1996; Hemmings *et al.*, (2000) & Robertson, Watt & Galloway (2004); rather than a single bout followed by a prolonged period of massage. The WAnT has a high test-retest correlation for peak and average power, ranging between r^2=0.89 & 0.98 (Bar-Or, 1987), which was of particular importance, as the subjects were required to perform several WAnTs over the course of the investigation. Thus, if the mean power output data was highly correlated, then any differences seen during the recovery period would be due to the specific recovery methods, and not due to significant variations in the 30sec WAnT results.

AIMS

5.2 Aims

There are inconsistencies in the conclusions of research studies examining the effects of massage as a method of aiding exercise recovery. Consequently, the aim of the investigation presented in this chapter was to further explore and elucidate the effects of massage during recovery form intense exercise. Moreover, there is currently no research available to elucidate the effect of mechanical vibratory massage as a method of recovery from exercise.

There is paucity regarding the short term effects of vibratory massage as a method of recovery from exercise. Furthermore, there is very limited research investigating the effects of combining massage with exercise during the initial stages of recovery from exercise. Therefore, the aim of Investigation 4 was two fold; *a)* to elucidate the effects of vibratory leg massage; and *b)* compare the effect of continuous (45mins specific recovery) and combined recovery (combining 15mins with 30mins specific recovery) from a single bout of maximal intensity exercise.

a) Mechanical vibratory massage was included in Investigation 4 in order to determine whether this less tactile massage method could elicit a similar effect to manual massage. There is currently no published research substantiating the effectiveness of vibratory massage as a method of recovery from exercise, despite the beneficial anecdotal claims made by manufacturers. Therefore, any conclusions emanating from this present investigation will contribute to a greater understanding of vibratory massage as a method of recovery from exercise.

b) The intention during the combined recovery protocol (combining exercise with massage) was to enhance lactate clearance and minimise any drop in diastolic pressure, by combining continued low intensity cycling during the period when lactate concentration remained high (i.e. the first 15mins); proceeded by 30mins of manual leg massage (MM), vibratory leg massage (VM), or supine rest (R). This method of combined recovery would be applicable for use with athletes in sporting events which require short maximum exertions, which increases BLa, performed several times over the course of day e.g. track cycling championships, or swimming gala. During combined recovery, subjects completed the seven interventions detailed below in a random order:-

Continuous recovery	**Combined recovery**
CE+CE (45mins Continuous Cycling Exercise)	CE+R (15mins CE + 30mins R)
R+R (45mins Supine Rest)	CE+MM (15mins CE + 30mins MM)
MM+MM (45mins Manual leg Massage)	CE+VM (15mins CE + 30mins VM)
VM+VM (45mins Vibratory leg Massage)	

SPECIFIC MATERIALS AND METHODS

(Investigation 4)

5.3 Subjects

5.3.1 Each of the 10 male subjects (Table 5.1) (mean±SD: 22.3±2.0yrs, 74.2±8.9kg, and height 177.6±6.4cm) completed the seven recoveries from the WAnT in a different order (Table 5.2). The recovery period was 45mins.

Table 5.1 Age, height, weight and main participation sport of the 10 male subjects participating in Investigation 5.

Subject No.	Age	Height	Weight	Max HR	Main Sport
1	23	171	63.2	188	Triathlon
2	21	174	66.6	190	Boxing
3	24	180	78.6	195	Hockey
4	25	174	81	195	Running
5	24	179	74.2	187	Swimming
6	20	187	78.4	195	Basketball
7	24	169	64.9	200	Football
8	19	187	88.3	193	Basketball
9	22	182	82.3	192	Cycling
10	21	173	64.4	189	Cycling

Table 5.2 Randomly assigned recovery methods for each subject during Investigation 5.

Subject	1	2	3	4	5	6	7	8	9	10
MM	1	7	6	5	4	3	2	1	2	1
VM	2	1	7	6	5	4	3	3	4	7
CE	3	2	1	7	6	5	4	5	6	2
R	4	3	2	1	7	6	5	7	1	6
CE+MM	5	4	3	2	1	7	6	2	3	3
CE+VM	6	5	4	3	2	1	7	4	5	5
CE+R	7	6	5	4	3	2	1	6	7	4

All tests were performed in a 1hr postprandial condition and at an ambient room temperature of between 21 - 24°C.

5.4 Preliminary measurements

Maximal oxygen uptake and maximum heart rate was estimated a week prior to the experiment (detailed in Chapter 2). The results of the test were used to set the work rate for the recumbent cycling exercise recovery.

5.5 Warm up

Subjects were required to prepare for the exercise test with a 10min submaximal warm-up at 80watts (80rpm @ 1kg) on a calibrated Monark 818*E* weight loaded cycle ergometer (Monark Bodyguard, Varberg, Sweden).

5.6 Exercise Test

Wingate Anaerobic Test (WAnT): The WAnT was performed on a calibrated Monark 834*E* weight loaded cycle ergometer (Monark Bodyguard, Varberg, Sweden). The full braking load for the test was set at 7.5% bodyweight (Inbar, Bar-Or & Skinner, 1996) and was applied at maximum voluntary cadence. Toe clips were used on the pedals to maximise the use of both quadriceps and hamstring muscle groups. Subjects were given verbal encouragement during the 30sec test, but not given any indication of time remaining. On completion of the WAnT (Figure 5.1), the subjects were required to immediately stop pedalling, advised to dismount the cycle ergometer, and were told which specific recovery method they would be receiving for the recovery period. For the purposes of consistency, the T_{Zero} measurements were taken immediately on completion of the WAnT, and prior to the start of the recovery mode, whilst the subjects were lying in a supine position.

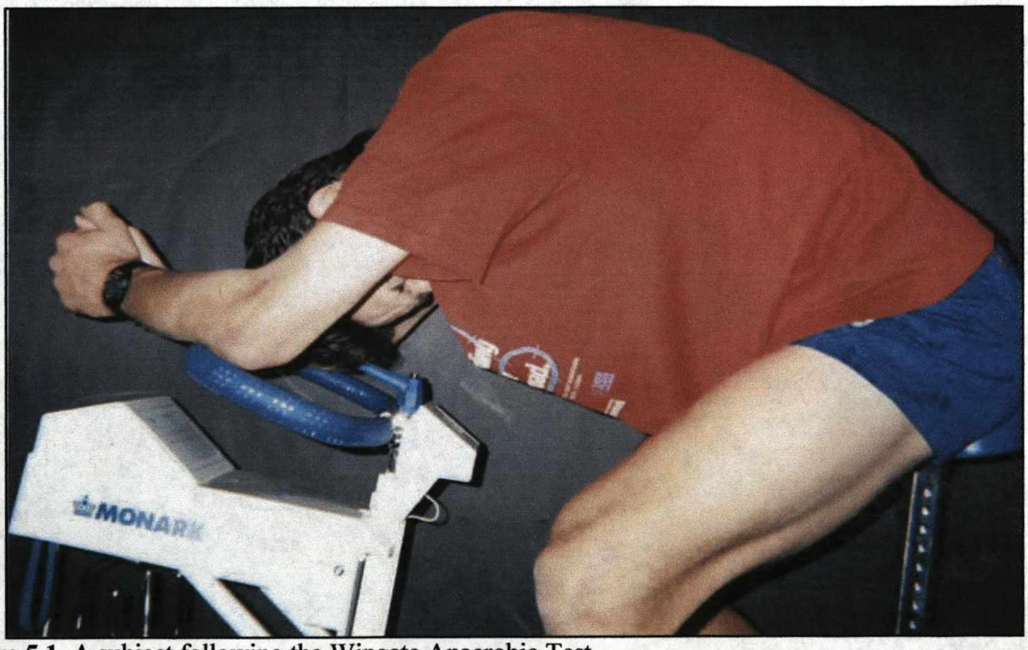


Figure 5.1 A subject following the Wingate Anaerobic Test.

5.7 Recovery Protocols

5.7.1 Manual Leg Massage (MM): The posterior aspect of the leg was massaged in a prone position, followed by the anterior in a supine position for the same time period. The general sequence of massage (manual and vibratory) is detailed in Table 5.3. Subjects were requested to remain still and quiet throughout.

5.7.2 Vibratory leg Massage (VM): The vibratory leg massage was administered using the U-shaped sponge (app. 230) to simulate effleurage at 30Hz, and using the 4-ball adaptor (app. 216) at 60Hz to simulate petrissage.

Table 5.3 Investigation 4: General sequence of leg massage (manual and vibratory) for prone then supine positions for continuous recovery (total time = 45mins).

Prone	Time (mins)	Supine	Time (mins)
Superficial effleurage of whole leg	1.75	Superficial effleurage of whole leg	1.75
Superficial effleurage of hamstrings	1	Superficial effleurage of quadriceps	1
Deep effleurage of hamstrings	1	Deep effleurage of quadriceps	1
Kneading of hamstrings	1	Kneading of quadriceps	1
Wringing of hamstrings	1	Wringing of quadriceps	1
Superficial effleurage of whole leg	1	Superficial effleurage of whole leg	1
Deep effleurage of calf	1	Deep effleurage of tibialis anterior	1
Kneading of the calf	1	Kneading of tibialis anterior	1
Deep effleurage of whole leg	1	Deep effleurage of whole leg	1
Superficial effleurage of whole leg	1.5	Superficial effleurage of whole leg	1.5

5.7.3 Rest (R): Subjects were required to adopt a prone position, followed by a supine position for the same time period.

5.7.4 Recumbent continuous cycling exercise (CE): Recumbent continuous exercise recovery was performed on a LifeCycle 9500HR recumbent cycle ergometer (LifeFitness, Unterschleissheim, Germany) at a cadence of 80rpm, using resistance to maintain a constant intensity (60%HR_{max}) (Figure 5.2). During the preliminary study by Jones & Cotterrell (1999), subjects had difficulty in maintaining a low enough intensity to achieve the target heart rate required after such a hard anaerobic test; therefore, the target heart rate was increased by 5%. In order to standardise the body position throughout the recovery methods, the cycling exercise during recovery was on a recumbent cycle, thus partly simulating the supine position adopted during Rest and manual leg massage. Previous research has shown that recumbent cycling has no significantly greater effect on biomechanical movement, fibre recruitment, heart rate and blood pressure compared to upright cycling at the same work rate

(Hakansson & Hull, 2002; Gregor *et al*., 2002; and Chang, Qi, Larson, Rose-Gottron & Cooper (2005)). However, Chang, Qi, Larson, Rose-Gottron & Cooper (2005) reported that subjects perceived that they were more comfortable and relaxed on a recumbent cycle; and for the purposes of this experiment, this may have positive effects when assessing perception of feeling.

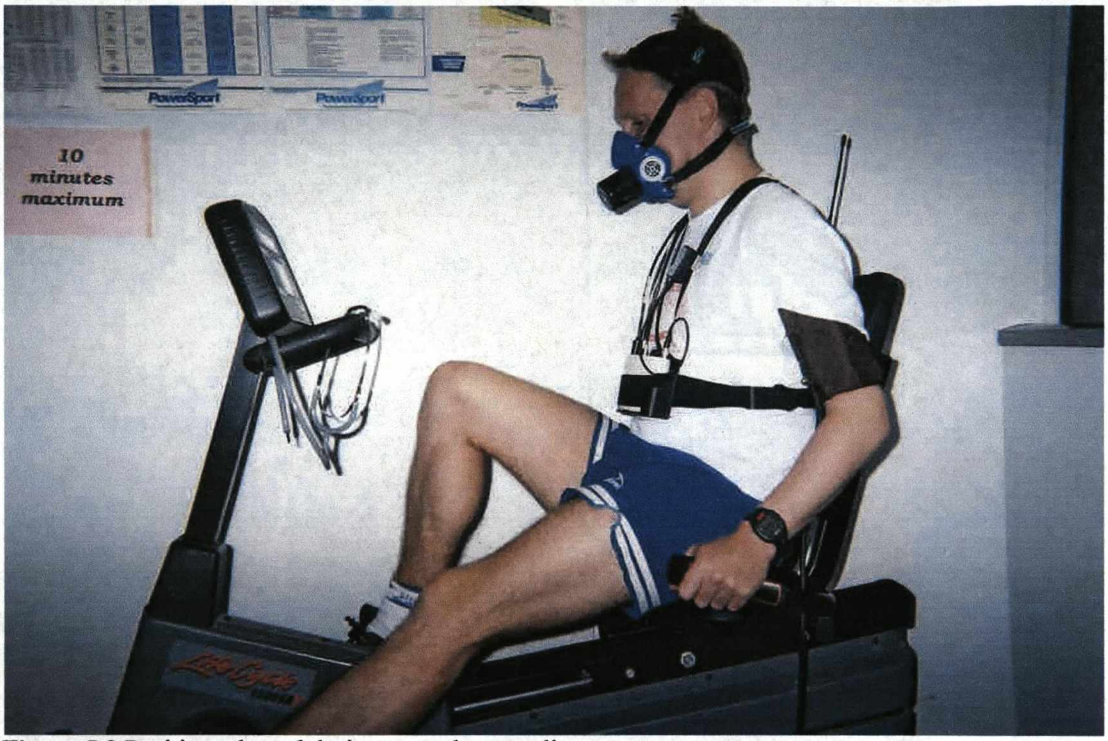


Figure 5.2 Position adopted during recumbent cycling.

5.7.5 Combined recovery: A combination of 15mins CE followed by either 30mins MM, VM or R.

5.8 Data collection

Protocols for rating of perceived exertion, blood lactate, heart rate, blood pressure, pulmonary ventilation, metabolic rate, leg skin & aural temperature and perception of feeling are detailed in Chapter 2. The values for metabolic rate and pulmonary ventilation are an average of data recorded in the previous minute; apart from immediately post WAnT where a 10sec average was taken.

5.9 Timeline of measurements

Prior to the baseline measurements, subjects rested for 5mins in a supine position in a quite room at an ambient temperature. The T_{Zero} measurement was taken immediately on completion of the WAnT, and prior to the start of the recovery mode. The 45min measurements were taken immediately on completion of the recovery mode whilst the subjects were laying in a supine position. The 15mins post WAnT measurement was taken prior to the change from cycling exercise (CE) to a different recovery mode (R, MM or VM) for the remaining 30mins of recovery. Table 5.4 details which measurements were taken, and when.

Table 5.4 Measurements taken at each time point during Investigation 4.

	BLa	BP	HR	Metabolic rate	Pulmonary ventilation	Body temperature	PoF
Baseline	✓	✓	✓	✓	✓	✓	✓
Warm up	✓	✓	✓	✓	✓		✓
T_{Zero}	✓	✓	✓	✓	✓		✓
3mins post	✓	✓	✓	✓	✓		✓
5mins post	✓	✓	✓	✓	✓		✓
10mins post	✓	✓	✓	✓	✓		✓
15mins post	✓	✓	✓	✓	✓		✓
20mins post	✓	✓	✓	✓	✓	✓	✓
30mins post	✓	✓	✓	✓	✓		✓
45mins post	✓	✓	✓	✓	✓	✓	✓

5.10 Statistical Analysis:

Parametric data are presented as Mean ± Standard deviation (SD). Prior to testing the experimental hypotheses, Shapiro-Wilks normality test and Levene's homogeneity of variance test were performed on all data; these checks revealed satisfactory outcomes. Repeated measures ANOVA and *post hoc* paired samples *t*-tests were performed to compare effects between conditions. Paired *t*-test analysis was also used to compare post treatment to baseline. Non-parametric data are presented as Median ± InterQuartile Range (IQR). Data was analysed with Friedman's test and *post hoc* with Wilcoxon signed-rank test in order to compare effects between conditions. For correlation analysis, bivariate Pearson's correlation coefficient was calculated. The level of significance was taken as $p<0.05$.

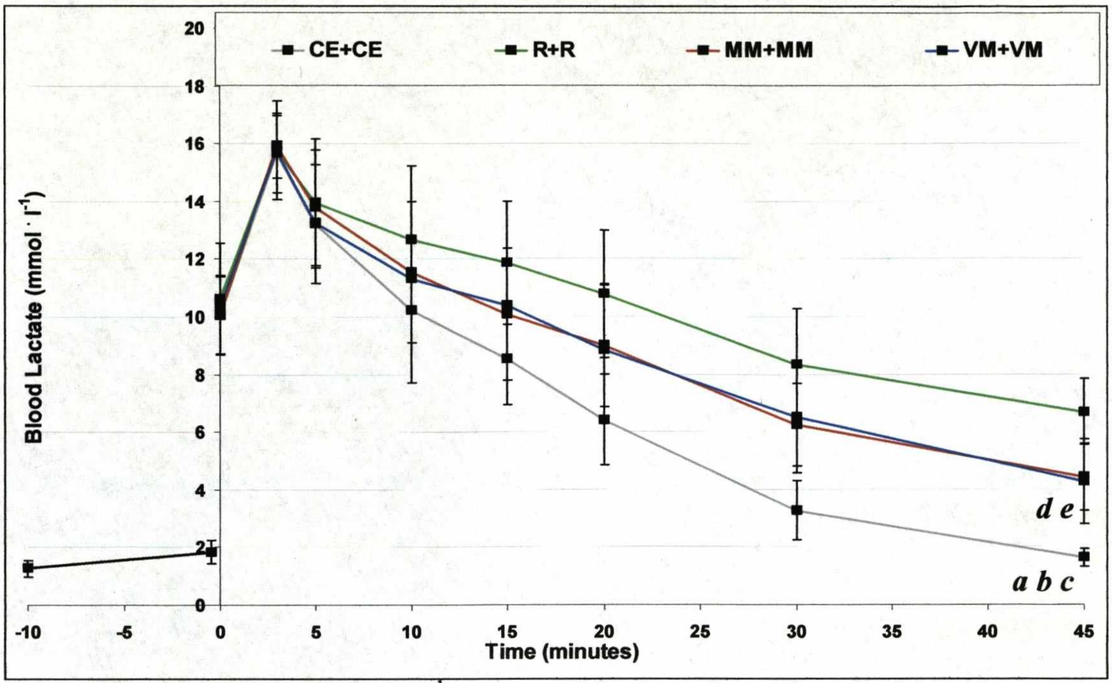


Figure 5.3a Blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE *vs* MM+MM, ***b*** = CE+CE *vs* VM+VM, ***c*** = CE+CE *vs* R+R, ***d*** = MM+MM *vs* R+R and ***e*** = VM+MM *vs* R+R (*n* = 10).

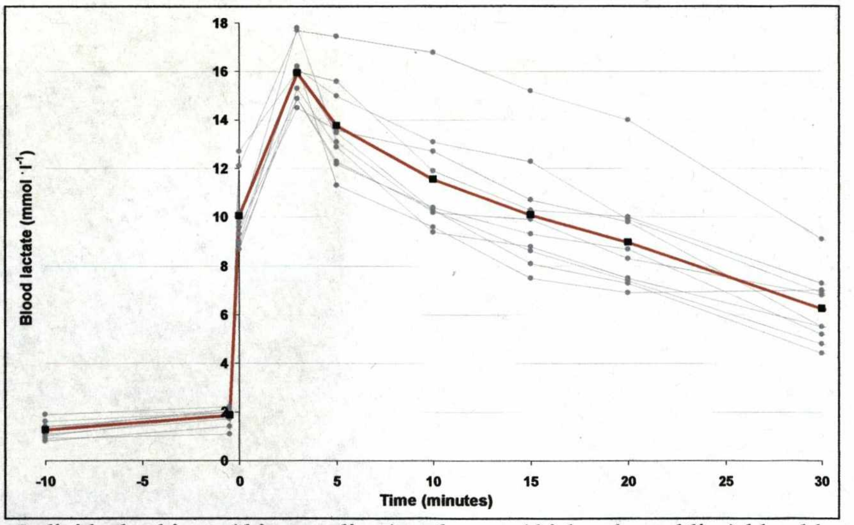


Figure 5.4a Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for continuous manual leg massage (MM+MM).

RESULTS

5.11 30sec Wingate Anaerobic Test

5.11.1 The mean power outputs (W · Kg^{-1}) between the seven WAnT trials (4 continuous and 3 combined) correlated highly (r^2 = 0.912), and therefore were not significantly different (p=0.0017) (Table 5.5). On completion of the WAnT, median RPE was 20 (IQR 19, 20) (Maximal Exertion).

Table 5.5 Mean power outputs (W · Kg^{-1}) for the seven conditions.

CE+CE	8.81±0.93
R+R	8.76±0.88
CE+R	8.57±0.75
MM+MM	8.71±0.83
CE+MM	8.53±0.84
VM+VM	8.62±0.65
CE+VM	8.68±0.73
Mean	**8.67±0.80**

5.12 The effect of massage on blood lactate clearance

5.12.1 Continuous recovery: Baseline BLa was 1.3±0.3mmol · l^{-1}. During continuous recovery, highest lactate concentration of 13.2±1.3mmol · l^{-1} was seen at 3mins post (Figure 5.3a). The BLa concentrations for MM+MM and VM+VM were significantly lower (p<0.01) than that of R+R, and by 45mins BLa concentration remained high at 6.7±1.1mmol · l^{-1} for R+R, but had decreased to 4.2±1.2 mmol · l^{-1} and 4.1±0.8mmol · l^{-1} for MM and VM respectively. The BLa for CE+CE was 1.6±0.3 mmol · l^{-1} at the same time point, only 0.5±0.3mmol · l^{-1} above baseline. Linear trend analysis showed that clearance time from highest lactate down to baseline was estimated at 55±4.9mins for MM+MM, 54±5.6mins for VM+VM, 46±1.9mins for CE+CE, and 70±6.9mins for R. Figure 5.4a and Figure 5.4b demonstrate that for MM and VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

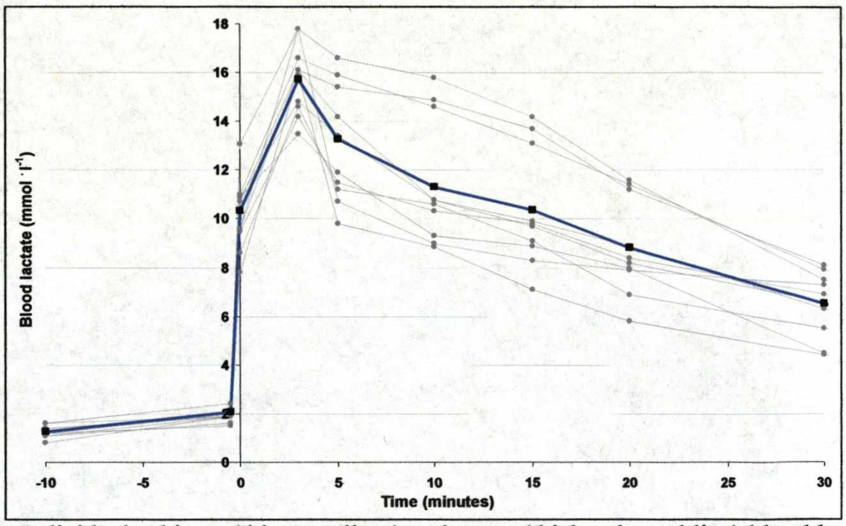


Figure 5.4b Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for continuous vibratory leg massage (VM+VM).

5.12.2 Combined recovery: During combined recovery, by 45mins BLa concentration was 5.2±1.3mmol · l^{-1} for CE+R, but had decreased to 3.2±1.1mmol · l^{-1} and 3.5±1.5mmol · l^{-1} for CE+MM and CE+VM respectively (Figure 5.3b). These values were lower, but not significantly so, than the respective values for combined recovery (MM+MM and VM+VM). The values for R+R and CE+R were significantly different at 45mins post (p=0.008). The estimated total clearance time to the baseline was lower for all three conditions at 50±6.2mins for CE+MM, 49±5.1mins for CE+VM and 60±6.2mins for CE+R, compared to continuous recovery. Figure 5.5a and Figure 5.5b demonstrate that for MM and VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

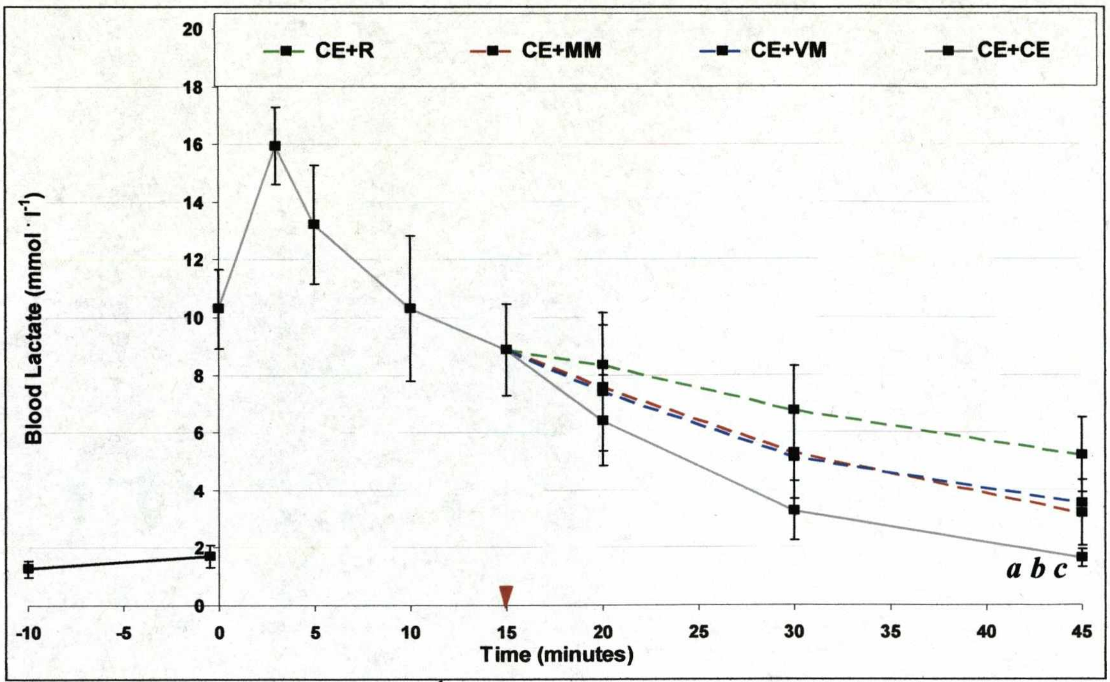


Figure 5.3b Blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R)). Significant differences ***a*** = CE+CE *vs* CE+MM, ***b*** = CE+CE *vs* CE+VM and ***c*** = CE+CE *vs* CE+R (n = 10). ▼ Change in recovery method following 15mins cycling exercise.

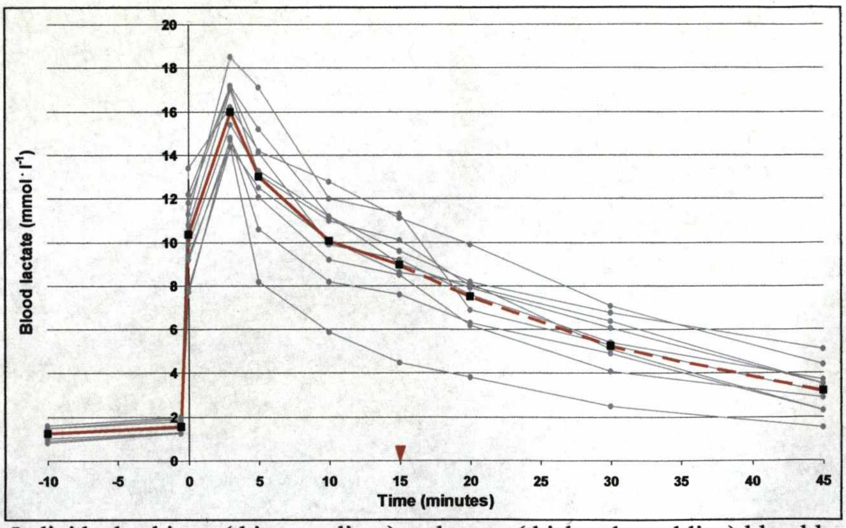


Figure 5.5a Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for combined cycling exercise and manual leg massage (CE+MM). ▼ Change in recovery method following 15mins cycling exercise.

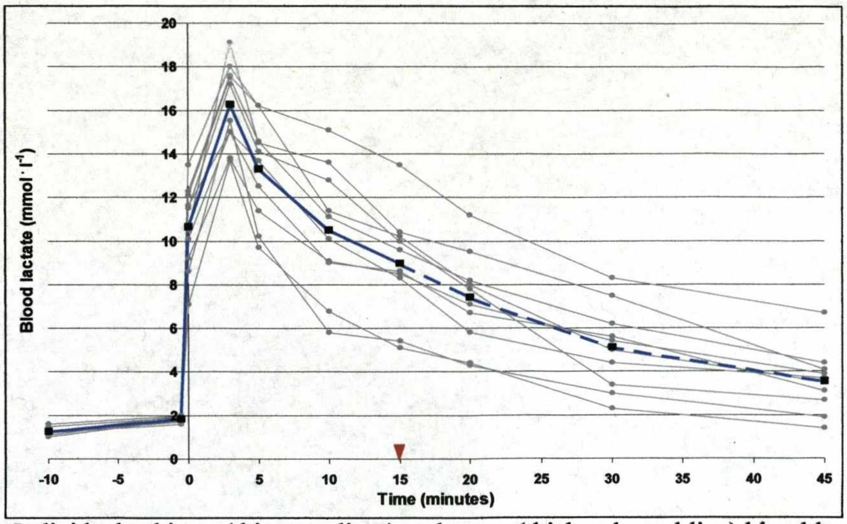


Figure 5.5b Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for combined cycling exercise and vibratory leg massage (CE+VM). ▼ Change in recovery method following 15mins cycling exercise.

In conclusion, manual leg massage (MM+MM) and vibratory leg massage (VM+VM) were equally effective at decreasing blood lactate concentration, and both were significantly more effective than Rest (R+R), but not as effective as recumbent cycling exercise (CE+CE). Similarly, massage combined with cycling exercise (CE+MM and CE+VM) was more effective than Rest (CE+R).

5.13 The effect of massage on heart rate

5.13.1 Continuous recovery: Baseline HR was 67.9±9.2bpm. On completion of the WAnT, heart rate increased to greater than 180bpm (Figure 5.6a). This was followed by a decrease over time for all recovery methods. At 45mins post WAnT the HR for MM+MM (80.7±12.5bpm) and VM+VM (81.1±6.7bpm) were lower, but not significantly so, than that of R+R (89.2±12.2bpm). All were significantly lower ($p<0.0001$) than CE+CE. The HR for CE+CE remained elevated at 117.4±2.5bpm throughout the 45mins recovery period.

5.13.2 Combined recovery: For combined recovery (Figure 5.6b), at 45mins the HR for CE+MM (89.1±7.4bpm) and CE+VM (87.7±9.1bpm) were again somewhat lower than that of CE+R (93.4±10.2bpm). Analysis showed that there was a significant difference between the 45mins post HR for MM+MM *vs* CE+MM ($p=0.041$). All remained significantly lower than CE+CE ($p<0.001$).

In conclusion, the heart rate for manual and vibratory leg massage remained lower than Rest throughout the 45min recovery period.

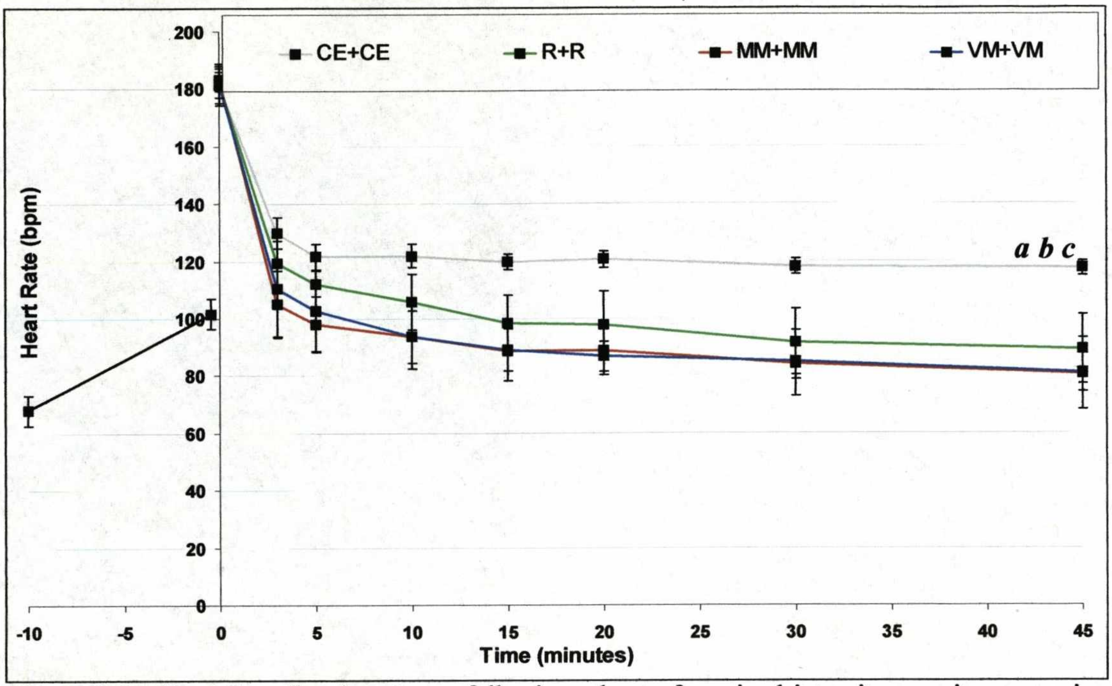


Figure 5.6a Heart Rate (bpm) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ($p<0.0001$) ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE vs VM+VM, *c* = CE+CE vs R+R ($n = 10$).

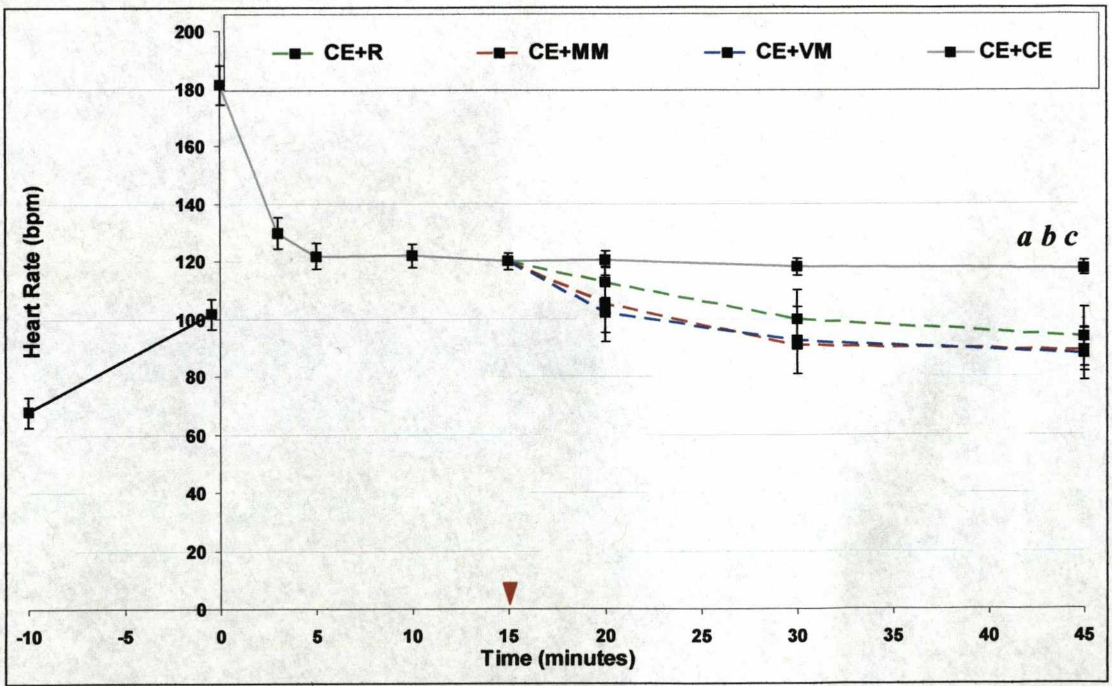


Figure 5.6b Heart Rate (bpm) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ($p<0.001$) ***a*** = CE+CE vs CE+MM, ***b*** = CE+CE *vs* CE+VM, ***c*** = CE+CE *vs* CE+R ($n = 10$). ▼ Change in recovery method following 15mins cycling exercise.

5.14 The effect of massage on systolic and diastolic blood pressure

5.14.1 Systolic continuous and combined recovery: Baseline systolic blood pressure was 113.8±7.1mmHg. The highest SBP was seen immediately after the WAnT, followed by a gradual decrease over time in all recovery methods. This corresponded with a similar trend in the heart rate. The SBP for CE+CE was significantly higher (p<0.001) at 45mins post than MM+MM, VM+VM and R+R during continuous recovery (Figure 5.7a). There was no significant difference between the massage conditions at any time point. During the combined conditions (Figure 5.10) a similar trend was seen throughout the 45mins.

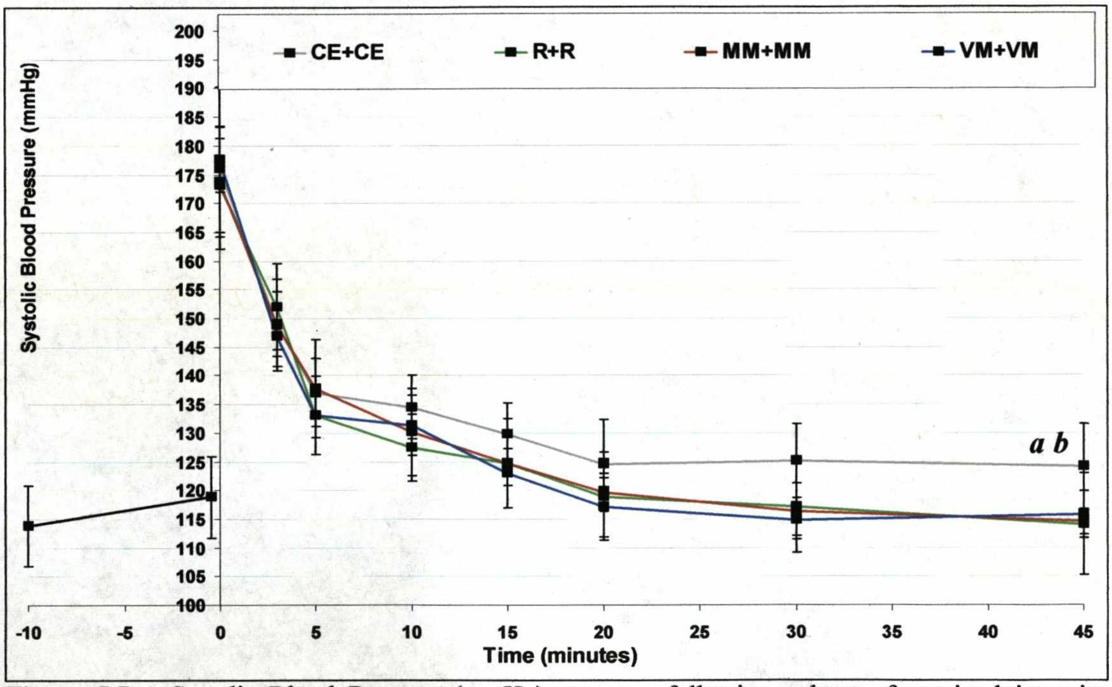


Figure 5.7a Systolic Blood Pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE vs VM+VM and c = CE+CE vs R+R (n = 10).

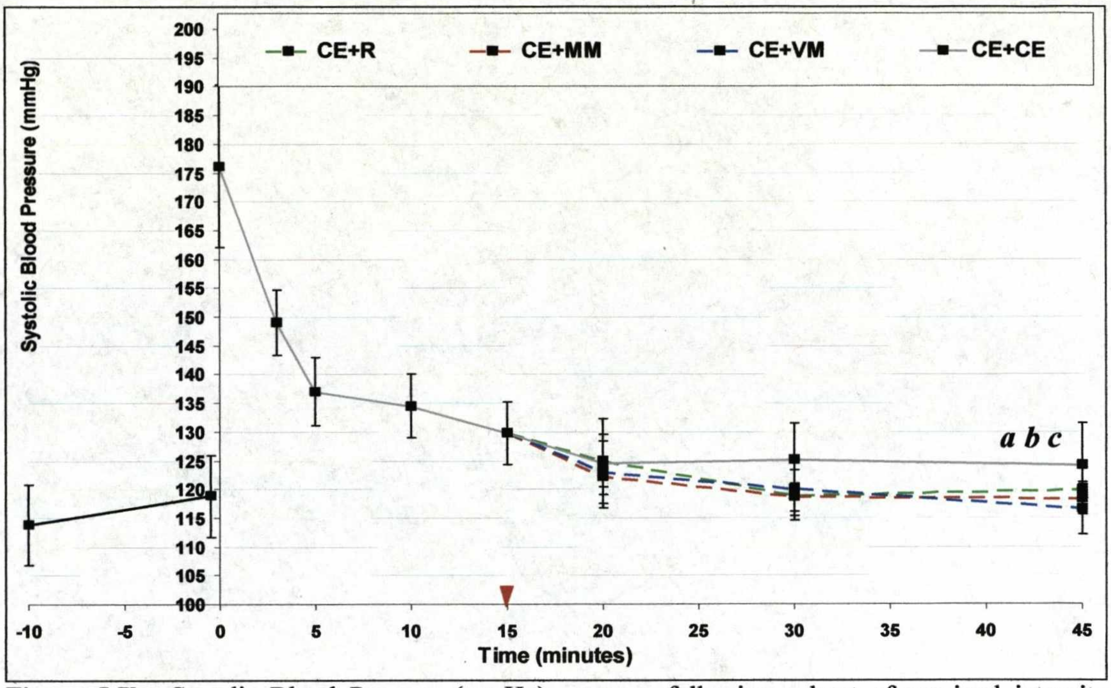


Figure 5.7b Systolic Blood Pressure (mmHg) response following a bout of maximal intensity comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences at 45mins post ***a*** = CE+CE *vs* CE+MM, ***b*** = CE+CE *vs* CE+VM, ***c*** = CE+CE *vs* CE+R (*n* = 10). ▼ Change in recovery method following 15mins cycling exercise.

5.14.2 Diastolic continuous recovery: Baseline diastolic blood pressure was 66.2±3.1mmHg (Figure 5.8a). A significant decrease was observed 3mins following the completion of the WAnT for all conditions except CE+CE. At 45mins, the DBP for R+R, MM+MM and VM+VM were 54.5±4.4mmHG, 60.5±2.5mmHG and 61.1±3.2mmHG respectively, remaining lower than the initial baseline of 66.1±3.4mmHG, 66.5±4.2mmHG and 66.9±3.1mmHG respectively. MM+MM and VM+VM did not improve DBP compared to R+R until 45mins.

5.14.3 Diastolic combined recovery: Due to the continuation of cycling for 15mins, DBP did not decrease within the first few minutes following the WAnT (Figure 5.8b). However, once subjects changed recovery mode for the remaining 30mins, DBP decreased significantly (p=0.017), and was not affected by massage. This diastolic undershoot was not as low as the values seen during continuous recovery, and by 45mins post DBP had returned to near normal for all conditions. The values for CE+R (p=0.005), CE+MM (p=0.0001) and CE+VM (p=0.01) were all significantly higher than their corresponding conditions during continuous recovery.

In conclusion, the results indicate that manual leg massage (MM+MM) or vibratory leg massage (VM+VM) did not prevent diastolic undershoot, similar to the trend seen during R+R. Although the DBP for CE+CE decreased slightly following the WAnT, it did not cause subjects to feel light-headed, nauseas or unwell. Continued cycling prevented diastolic undershoot in the first 15mins minutes following the WAnT, however it did not prevent it occurring when subjects changed position at 15mins.

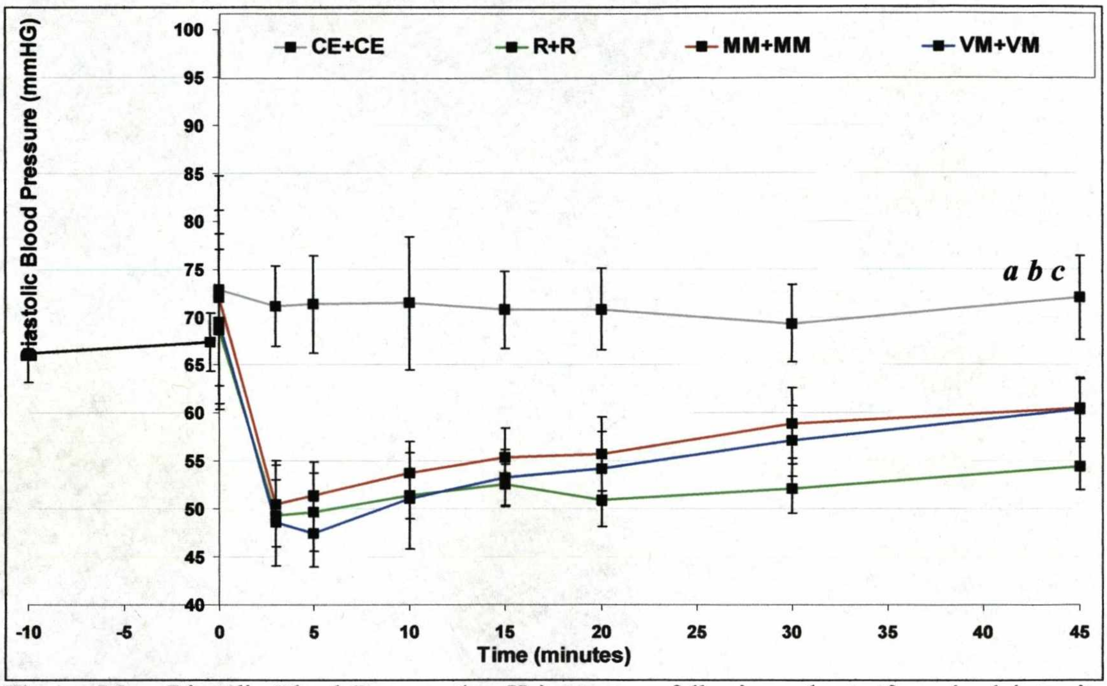


Figure 5.8a Diastolic Blood Pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE vs VM+VM, ***c*** = CE+CE vs R+R (*n* = 10).

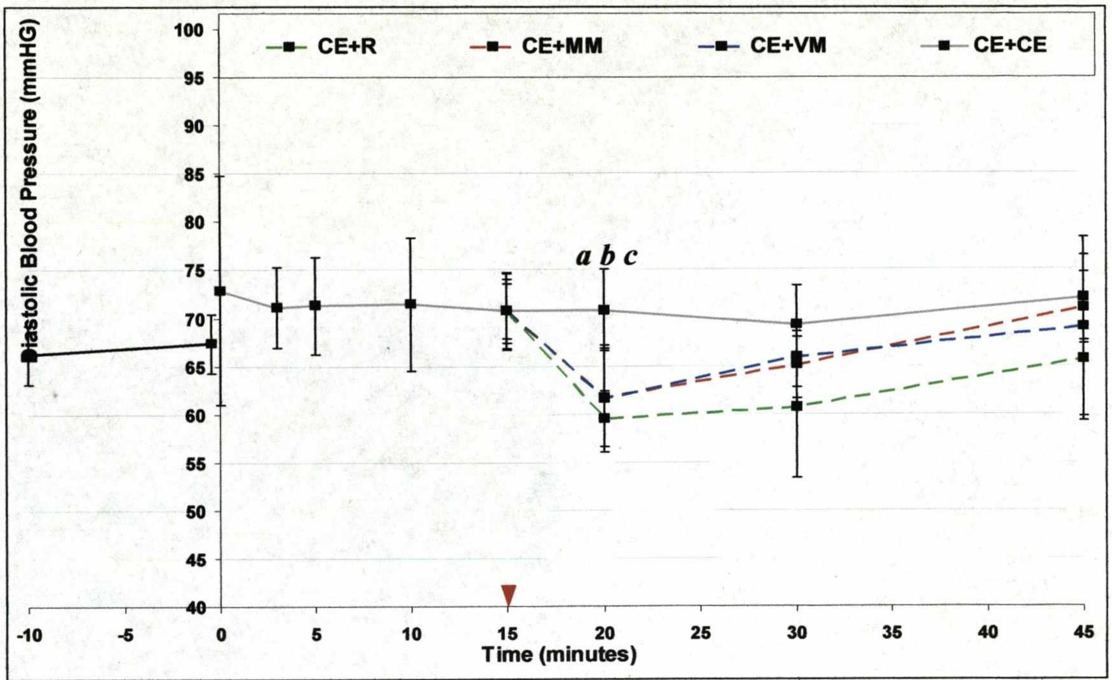


Figure 5.8b Diastolic Blood Pressure (mmHg) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences at 20mins post ***a*** = CE+CE vs CE+MM, ***b*** = CE+CE *vs* CE+VM, ***c*** = CE+CE *vs* CE+R (*n* = 10). ▼ Change in recovery method following 15mins cycling exercise.

5.15 The effect of massage on respiration

5.15.1 Respiratory rate continuous recovery: Baseline respiratory rate was 16.2±1.3cycles · min^{-1} (Table 5.6a). On completion of the WAnT this increased to 61.7±16.9cycles · min^{-1}, and was followed by a gradual decrease over time for all four recovery methods. At the end of the 45min recovery period, respiratory rate for MM+MM (15.5±1.7cycles · min^{-1}) was significantly lower (p<0.01) than that of R (17.1±1.8cycles · min^{-1}). Similarly, RR for VM+VM (16.2±1.3cycles · min^{-1}) was also lower than R+R, but not significantly so. All were significantly lower (p<0.0001) than the recumbent cycling method of recovery (30.3±5.7cycles · min^{-1}) which predictably remained elevated. There was no significant difference between MM+MM and VM+VM.

5.15.2 Tidal volume continuous recovery: Baseline tidal volume was 0.5±0.1litres (Table 5.6b), and on completion of the WAnT this increased to 2.4±1.0litres, and was followed by a gradual decrease over time for all four recovery methods. At the end of the 45min recovery period, V_T for MM+MM (0.7±0.1litres) was significantly higher (p<0.01) than that of R+R (0.5±0.2litres). Similarly, V_T for VM+VM (0.5±0.1litres) was also higher than R+R, but not significantly so. All were significantly lower ($p<0.0001$) than the recumbent cycling method of recovery (1.2±0.3litres) which predictably remained elevated. There was no significant difference between MM+MM and VM+VM.

Table 5.6a Respiratory variables for CE at baseline, during warm up, and on completion of a bout of maximal intensity exercise cont'd.. ($n = 10$).

	Baseline	**During warm up**	**On completion of WAnT**
Respiratory rate (RR)	16.2±1.3	20.9±3.1	61.7±16.9
Tidal volume (V_T)	0.5±0.1	1.2±0.3	2.4±1.0
Pulmonary ventilation (PV)	8.1±1.1	25.1±3.6	148.1±23.9

Table 5.6b Respiratory variables following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R) ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE *vs* VM+VM, ***c*** = CE+CE *vs* R+R, and ***d*** = MM+MM *vs* R+R ($n = 10$).

	3mins post WAnT	**5mins post WAnT**	**10mins post WAnT**	**15mins post WAnT**	**20mins post WAnT**	**30mins post WAnT**	**45mins post WAnT**
Respiratory rate (RR)							
R+R	39.2±5.1	29.2±4.5	25.2±4.2	23.7±3.4	22.0±2.9	19.1±2.6	17.1±1.9
MM+MM	38.0±4.7	30.3±4.2	26.4±3.9	22.2±3.8	21.3±2.1	17.5±2.1	15.5±1.7***d***
VM+VM	39.7±4.9	31.2±4.5	24.5±3.8	23.1±3.9	21.5±1.9	17.9±1.8	16.2±1.3
CE+CE	38.4±5.1	32.3±4.7	31.6±4.1	30.5±4.6	30.4±5.1	29.8±4.9	30.3±5.7***abc***
Tidal volume (V_T)							
R+R	1.5±0.7	1.2±0.5	0.9±0.3	0.8±1.0	0.7±0.2	0.5±0.1	0.5±0.2
MM+MM	1.5±0.6	1.1±0.4	0.8±0.4	0.8±0.09	0.6±0.1	0.6±0.1	0.7±0.1***d***
VM+VM	1.5±0.6	1.1±0.6	0.9±0.5	0.8±0.2	0.7±0.1	0.6±0.1	0.5±0.1
CE+CE	1.5±0.5	1.5±0.5	1.4±0.4	1.4±0.5	1.3±0.4	1.2±.04	1.2±0.3***abc***
Pulmonary ventilation (PV)							
R+R	59.9±6.5	34.7±4.8	22.4±3.9	18.0±3.6	14.4±2.7	9.9±1.4	9.0±1.4
MM+MM	57.0±6.1	33.5±4.4	22.1±4.1	17.9±4.0	13.6±2.3	10.2±1.2	10.4±1.7
VM+VM	58.4±5.9	34.7±5.1	21.7±3.7	18.3±3.4	14.1±2.9	10.0±1.1	8.9±1.9
CE+CE	57.6±5.7	48.4±5.9	44.2±5.1	42.7±4.7	40.5±4.5	35.2±4.3	36.4±4.7***abc***

5.15.3 Respiratory rate combined recovery: At 45mins (Table 5.7a) CE+RR for CE+MM (17.1±2.1cycles · min^{-1}) was once again significantly lower ($p=0.013$) than CE+R (18.4±2.6cycles · min^{-1}) (Tabl4 5.7b). There was no difference between VM+VM and R+R. There was no significant difference between the values for pulmonary ventilation between CE+MM, CE+VM and CE+R. All values for CE+CE were significantly higher than the three other recovery methods. There was no significant difference between MM+MM and VM+VM.

Table 5.7a Respiratory variables for CE following a bout of maximal intensity exercise (n = 10). Change in recovery method following 15mins cycling exercise.

	Baseline	During warm up	On completion of WAnT	3mins post WAnT	5mins post WAnT	10mins post WAnT	15mins post WAnT
Respiratory rate (RR)	16.2±1.3	20.9±3.1	61.7±16.9	38.4±5.1	32.3±4.7	31.6±4.1	30.5±4.6
Tidal volume (V_T)	0.5±0.1	1.2±0.3	2.4±1.0	1.5±0.5	1.5±0.5	1.4±0.4	1.4±0.5
Pulmonary ventilation (PV)	8.1±1.1	25.1±3.6	148.1±23.9	57.6±5.7	48.4±5.9	44.2±5.1	42.7±4.7

Table 5.7b Respiratory variables following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+CE *vs* CE+R, ***b*** = CE+CE *vs* MM+MM, ***c*** = CE+CE *vs* CE+R, and ***d*** = CE+MM *vs* CE+R (n = 10).

	20mins post WAnT	30mins post WAnT	45mins post WAnT
Respiratory rate (RR)			
CE+R	22.1±3.2	19.9±2.7	18.4±2.6
CE+MM	23.2±2.9	18.9±3.1	17.1±2.1***d***
CE+VM	24.5±3.3	19.1±2.6	18.1±2.5
CE+CE	30.4±5.1	29.8±4.9	30.3±5.7***abc***
Tidal volume (V_T)			
R+R	1.1±0.3	0.8±0.3	0.7±0.2
MM+MM	1.1±0.5	0.9±0.2	0.8±0.1***d***
VM+VM	1.0±0.3	0.8±0.1	0.7±0.3
CE+CE	1.3±0.4	1.2±.04	1.2±0.3***abc***
Pulmonary ventilation (PV)			
R+R	23.5±4.1	15.9±3.4	12.3±3.2
MM+MM	24.5±4.2	17.0±2.9	13.7±3.3
VM+VM	24.1±3.9	15.3±3.2	12.4±3.6
CE+CE	39.5±4.5	35.8±4.3	36.4±4.7***abc***

5.15.4 Pulmonary ventilation: From a baseline of 8.1±1.1 l · min^{-1} ventilation increased to 148.1±23.9 l · min^{-1} following the WAnT. During recovery, there was no significant difference between manual and vibratory massage at any time point. Furthermore, despite the significant decrease in RR seen for manual massage (compared to Rest), due to the increase in V_T there was no significant difference in pulmonary ventilation.

In conclusion, manual massage significantly decreased respiratory rate and increased tidal volume compared to Rest during recovery. There was no effect on pulmonary ventilation. Furthermore, there was no significant difference between manual and vibratory massage.

5.16 The effect of massage on oxygen uptake and carbon dioxide output

5.16.1 Oxygen uptake continuous recovery: Oxygen uptake (Figure 5.9a) increased significantly from 4.55±0.7ml O_2 kg^{-1} min^{-1} to 45.9±8.7ml O_2 kg^{-1} min^{-1} following the WAnT. The values for R+R, MM+MM and VM+VM decreased over time, and a comparison of the respective VO_2 values at 45mins post showed that for MM+MM (6.0±0.8ml O_2 kg^{-1} min^{-1}), VM+VM (5.7±0.9ml O_2 kg^{-1} min^{-1}) and R+R (4.6±1.1ml O_2 kg^{-1} min^{-1}) VO_2 had returned to near the baseline. The VO_2 for CE+CE remained relatively constant throughout the recovery period (15.6±1.8ml O_2 kg^{-1} min^{-1}) and there was a significant difference between CE+CE and the other three conditions (p=0.00012) throughout recovery.

5.16.2 Oxygen uptake combined recovery: For combined recovery, VO_2 began to decrease following the cessation of the 15mins continued cycling; and by 45mins were only marginally above the baseline (CE+MM (7.2±0.9ml O_2 kg^{-1} min^{-1}), CE+VM (6.7±1.2ml O_2 kg^{-1} min^{-1}) and (CE+R (5.9±1.1ml O_2 kg^{-1} min^{-1}) respectively) (Figure 5.9b).

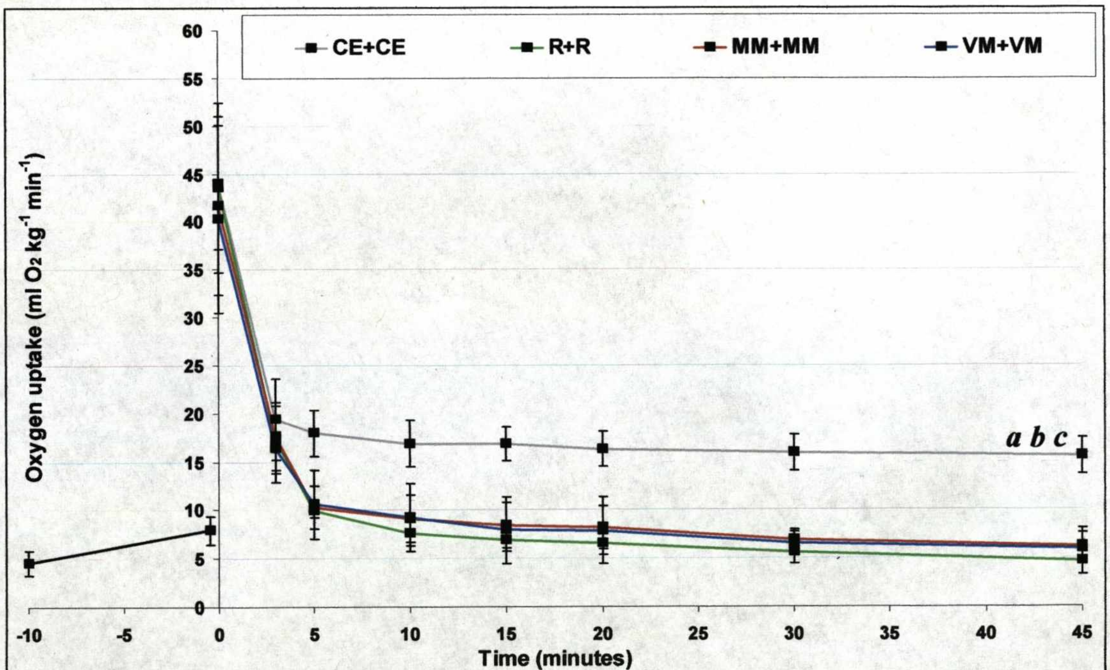


Figure 5.9a Oxygen uptake (ml O_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE *vs* MM+MM, ***b*** = CE+CE *vs* VM+VM and ***c*** = CE+CE *vs* R+R (n = 10).

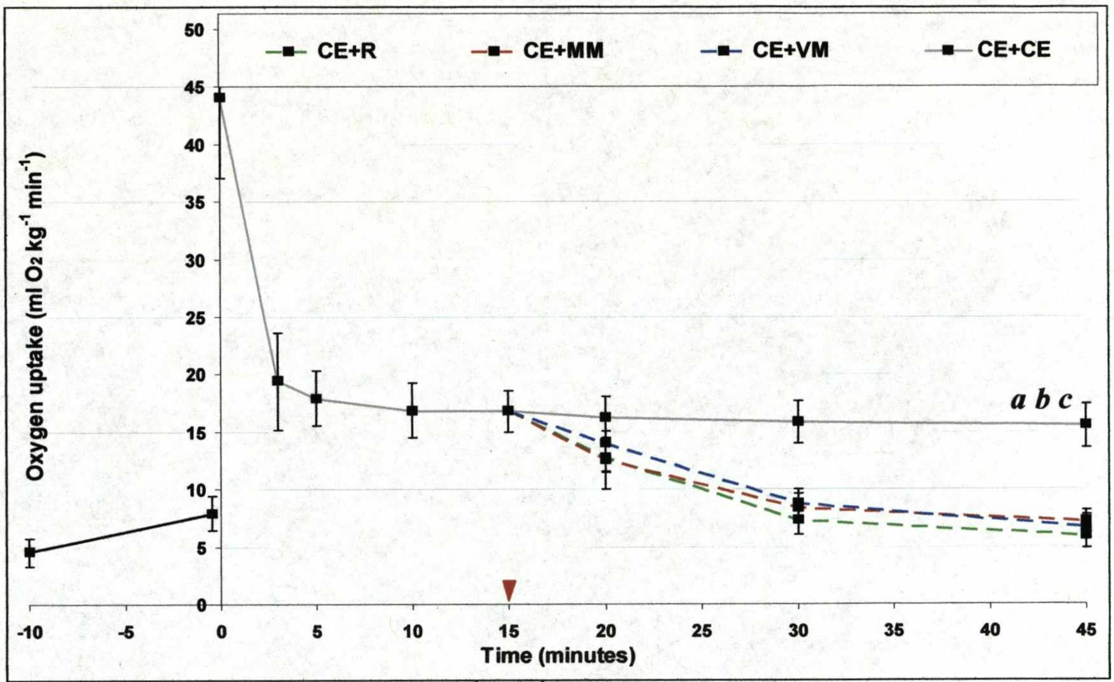


Figure 5.9b Oxygen uptake (ml O_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+CE *vs* CE+MM, ***b*** = CE+CE *vs* CE+VM and ***c*** = CE+CE *vs* CE+R (*n* = 10). ▼ Change in recovery method following 15mins cycling exercise.

5.16.3 Carbon dioxide output: Analysis showed no significant differences between VCO_2 output for MM+MM, VM+VM and R+R; however, all were significantly lower ($p<0.001$) than CE throughout the recovery period. By 45mins post, VCO_2 for MM+MM (4.5±0.7ml CO_2 kg^{-1} min^{-1}), VM+VM (4.7±1.0ml CO_2 kg^{-1} min^{-1}) and R+R (3.8±0.9ml CO_2 kg^{-1} min^{-1}) had returned to the baseline.

5.16.4 RER continuous recovery: Baseline respiratory exchange ratio was 0.74±0.03 (Figure 5.10a). This increased to 1.38±0.11 (CE+CE), 1.42±0.14 (MM+MM), 1.41±0.14 (VM+VM) and 1.44±0.12 (R+R) at 3mins post WAnT, reflecting considerable respiratory acidosis during the early part of the recovery phase for all conditions. RER then began to decrease, but at 45mins had not returned to baseline (0.85±0.03 (CE+CE), 0.82±0.03 (MM+MM), 0.81±0.03 (VM+VM) and 0.85±0.03 (R+R). Subsequent analysis showed that RER was highly correlated with BLa (r^2 = 0.82 (MM+MM) and 0.84 (VM+VM) and 0.80 (R+R)).

5.16.3 RER combined recovery: For combined recovery at 45mins post RER remained above baseline for all recovery methods (0.82±0.03 (CE+CE), 0.80±0.04 (CE+MM), 0.79±0.05 (CE+VM) and 0.84±0.03 (CE+R)) (Figure 5.10b).

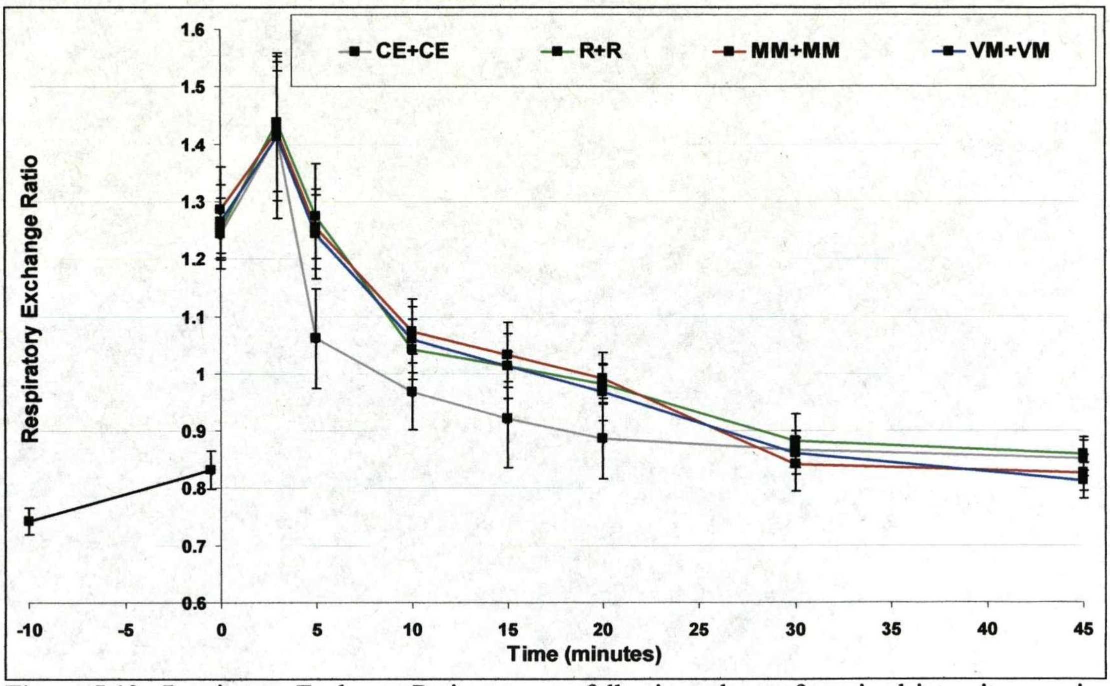


Figure 5.10a Respiratory Exchange Ratio response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R) (n = 10).

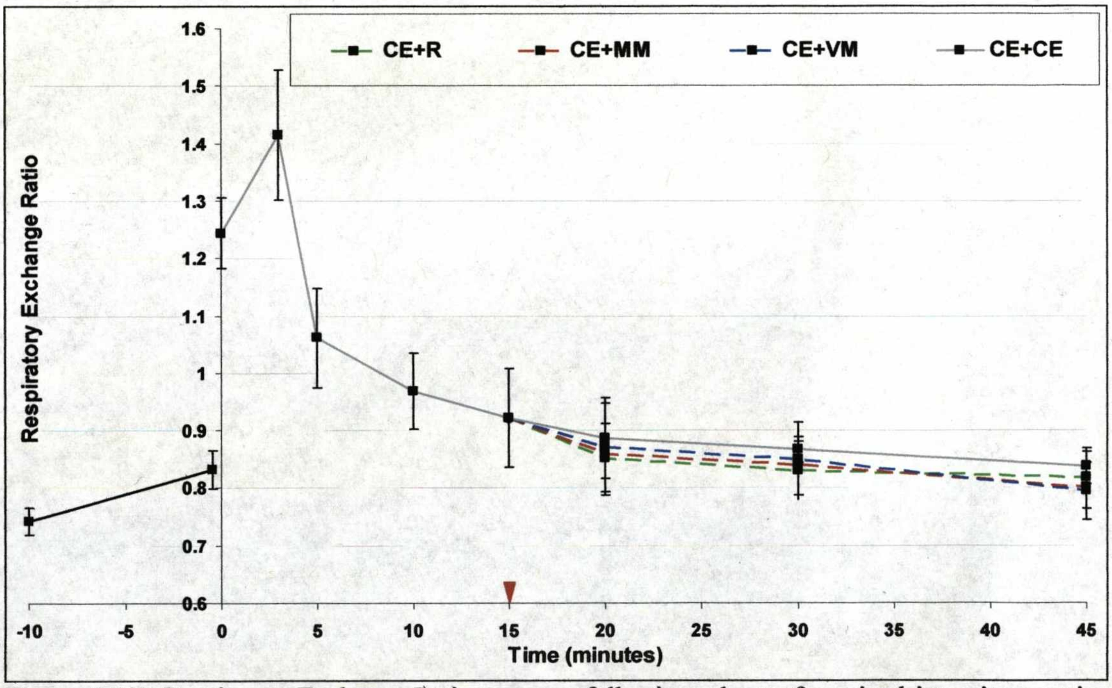


Figure 5.10b Respiratory Exchange Ratio response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). ▼ Change in recovery method following 15mins cycling exercise (n = 10).

In conclusion, MM+MM or VM+VM had no greater effect on oxygen uptake and carbon dioxide output compared to R+R, either during continuous recovery, or by combining with CE in the first 15mins of recovery.

5.17 The effect of massage on body temperature (Leg_{Temp} and $Aural_{Temp}$)

5.17.1 Leg_{Temp} continuous recovery: Leg_{Temp} was taken for five minutes at baseline, 20mins and 45mins post WAnT (Table 5.8). Baseline Leg_{Temp} was 31.5±0.71°C. The Leg_{Temp} for MM+MM and VM+VM were significantly higher than R+R at both 20mins and 45mins post. At 45mins, the Leg_{Temp} for R+R was 31.7±0.7°C, with the values for MM+MM and VM+VM remaining elevated at 33.5±1.0°C and 33.8±0.9°C respectively. The Leg_{Temp} for CE+CE at the same time point was 32.3±0.5°C. There was no significant difference between manual or vibratory massage.

5.17.2 Leg_{Temp} combined recovery: Leg_{Temp} during combined recovery followed the same trend as continuous recovery. The Leg_{Temp} for CE+MM and CE+VM were significantly higher than CE+R at both 20mins and 45mins post. At 45mins, the Leg_{Temp} for CE+R was 32.1±0.9°C, with the values for CE+MM and CE+VM remaining elevated at 34.4±0.7°C and 34.9±0.8°C respectively (Table 5.9). There was no significant difference between manual or vibratory massage.

Table 5.8 Leg temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = MM+MM *vs* CE+CE (During), ***b*** = MM+MM *vs* R+R (During), ***c*** = MM+MM *vs* R+R (Post), ***d*** = VM+VM *vs* CE+CE (During), ***e*** = VM+VM *vs* R+R (During) and ***f*** = VM+VM *vs* R+R (Post) (*n* = 10).

	Baseline	**During (20-25mins)**	**Immediately Post Recovery (45-50mins)**
CE+CE	31.5±0.7	32.2±0.5	32.3±0.5
R+R	31.5±0.7	31.6±0.7	31.7±0.7
MM+MM	31.5±0.7	33.5±1.0 ***a b***	33.1±1.0 ***c***
VM+VM	31.5±0.7	33.9±1.0 ***d e***	32.8±0.9 ***f***

Table 5.9 Leg temperature (°C) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+MM *vs* CE+CE (During), ***b*** = CE+MM *vs* CE+R (During), ***c*** = CE+MM *vs* CE+R (Post), ***d*** = CE+VM *vs* CE+CE (During), ***e*** = CE+VM *vs* CE+R (During) and ***f*** = CE+VM *vs* CE+R (Post) (p<0.05) (*n* = 10).

	Baseline	**During (20-25mins)**	**Immediately Post Recovery (45-50mins)**
CE+R	31.5±0.7	32.5±0.9	32.1±0.6
CE+MM	31.5±0.7	34.4±1.0 ***a b***	33.9±0.7 ***c***
CE+VM	31.5±0.7	34.9±0.8 ***d e***	34.2±0.8 ***f***
CE+CE	31.5±0.7	32.2±0.5	32.3±0.5

5.17.3 Aural$_{Temp}$ continuous recovery: Baseline measurement of Aural$_{Temp}$ was 36.8±0.3°C. A small increase was observed in Aural$_{Temp}$ for all conditions following the completion of the WAnT (Figure 5.11a). During continuous recovery, there was no significant difference seen between MM+MM or VM+VM. The 45mins post Aural$_{Temp}$ was 37.9±0.15°C for CE+CE, but lower for the other three conditions (R+R 37.0±0.19°C, MM+MM 37.3±0.11°C and VM+VM 37.4±0.15°C).

5.17.4 Aural$_{Temp}$ combined recovery: For combined recovery, following the change in recovery mode at 15mins, Aural$_{Temp}$ began to slowly decrease (Figure 5.11b). The temperatures for both massage conditions, 37.7±0.17°C (CE +MM) and 37.7±0.2°C (CE+VM)) remained somewhat higher than that of CE+R (37.3±0.12°C). All remained higher than baseline (36.8±0.25°C). A comparison of continuous and combined recovery methods showed that at 45mins post Aural$_{Temp}$ was significantly higher for combined recovery (R+R *vs* CE+R (p=0.011), MM+MM *vs* CE+MM (p=0.009) and VM+VM *vs* CE+CM (p=0.032)).

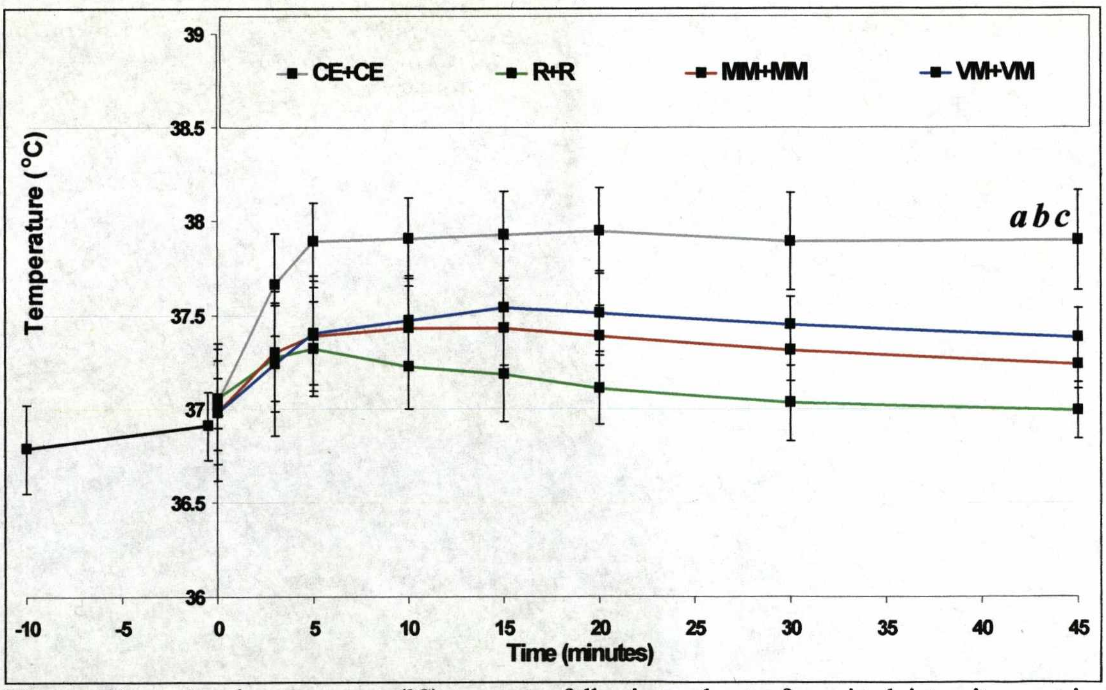


Figure 5.11a Aural temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = CE+CE vs MM+MM, ***b*** = CE+CE *vs* VM+VM, ***c*** = CE+CE *vs* R+R (n = 10).

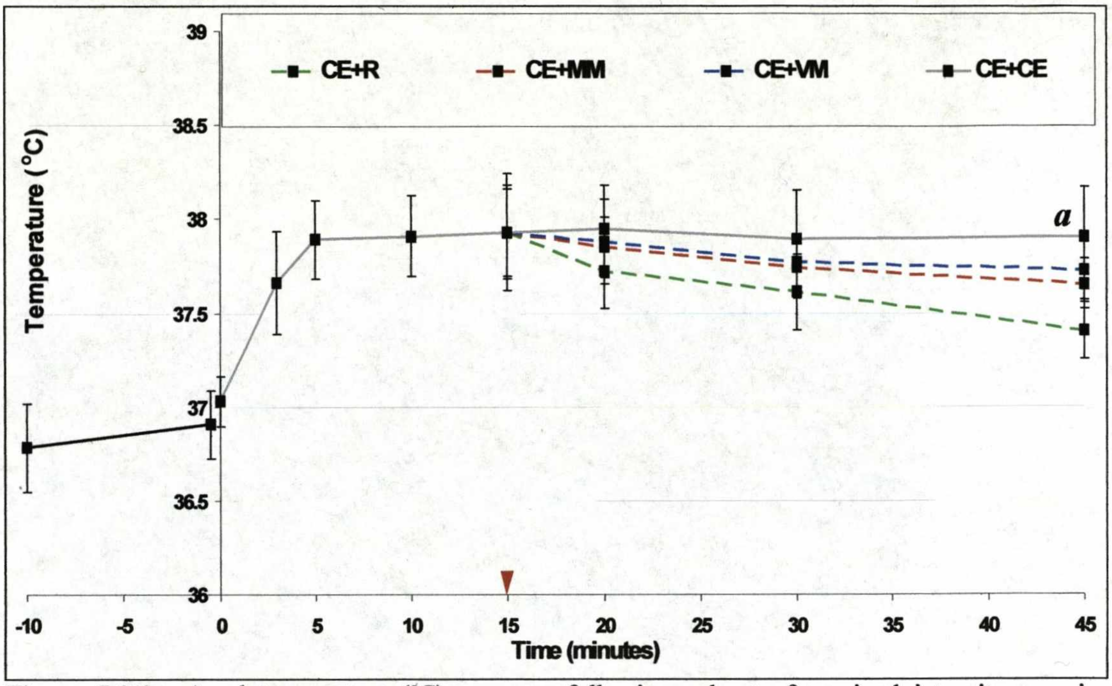


Figure 5.11b Aural temperature (°C) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg Massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+CE *vs* CE+R ▼ Change in recovery method following 15mins cycling exercise (n = 10).

5.18 The effect of massage on perception of feeling

5.18.1 Continuous recovery: With the completion of the WAnT, PoF decreased from +6 to -3 (IQR -2, -3.75) for all conditions. Feeling subsequently began to improve over the 45mins recovery period at different rates, with MM+MM being the superior method. Significant differences were seen between the PoF's for the four continuous conditions, and at 45mins post, values indicated that MM+MM had the greater effect; subjects perceived that they felt "Very Good" (+6). In contrast, during VM+VM (+4 IQR 3, 5) and CE+CE (+4 IQR 0.75, 5), subjects only reported feeling "Good". Moreover, during R+R subjects only reported a perception of feeling rating of "Fairly Good" (+1.5 IQR 1, 3) (Figure 5.12a).

5.18.2 Combined recovery: Following the WAnT, feeling began to steadily improve during continued cycling, until the change in recovery mode at 15mins post (Figure 5.12b). At 20mins post, five minutes after the change in position, PoF for CE+R decreased from +3 (IQR 0.5, 4) to +1 (IQR 0, 1.75), and at 45mins post, subjects only reported feeling 'Fairly Good' (2 IQR 1.25, 3). PoF for MM+MM and VM+VM continued to improve, and at 45mins post, the values were 6 (IQR 5.25, 6) ('Very Good') and 5 (IQR 4, 6) respectively, were significantly higher than CE+R (2

IQR 1.25, 3). A comparison between R+R and CE+R shows that replacing the first 15mins with CE did not improve PoF significantly. The 45mins post PoF for CE+VM was greater than the value during VM+VM.

In conclusion, the results clearly show a positive psychological effect exerted during manual leg massage, and to a slightly lesser degree vibratory massage. Despite manual leg massage not preventing diastolic undershoot, and not clearing lactate as effectively as CE+CE, it did have a greater impact on subject's perception of how they felt, and prevented any unpleasant side effects.

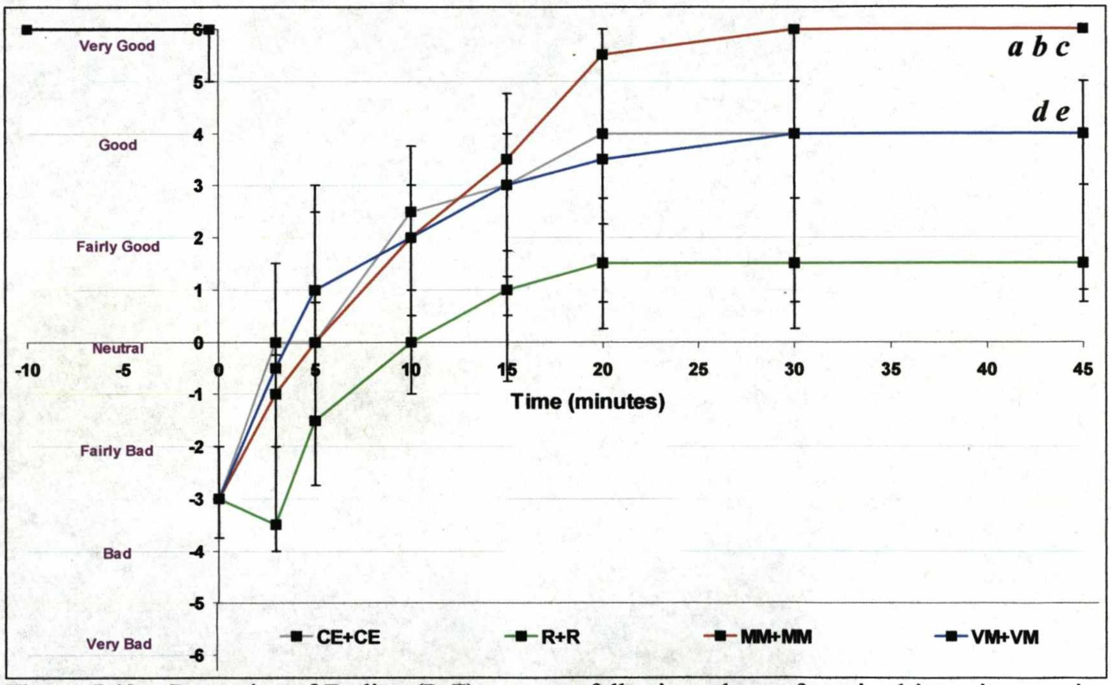


Figure 5.12a Perception of Feeling (PoF) response following a bout of maximal intensity exercise comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R). Significant differences ***a*** = MM+MM *vs* R+R, ***b*** = MM+MM vs CE+CE, ***c*** = MM+MM *vs* VM+VM, ***d*** = VM+VM *vs* R+R and ***e*** = CE+CE *vs* R+R (*n* = 10).

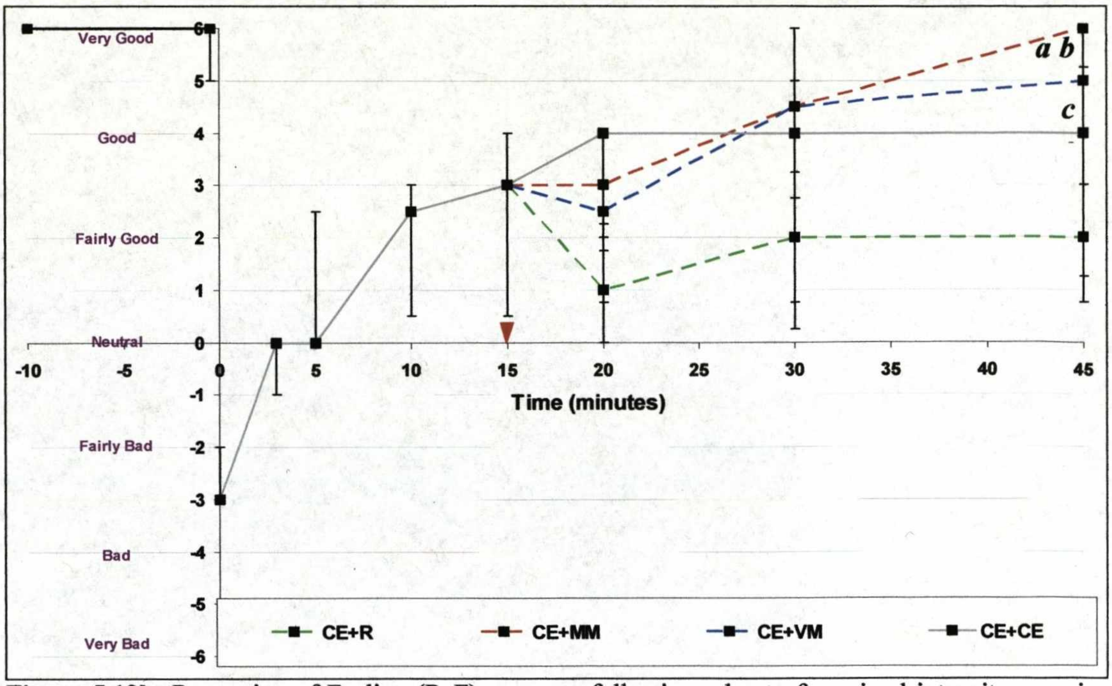


Figure 5.12b Perception of Feeling (PoF) response following a bout of maximal intensity exercise comparing for cycling exercise (CE+CE), cycling exercise + manual leg massage (CE+MM), cycling exercise + vibratory leg massage (CE+VM) and cycling exercise + rest (CE+R). Significant differences ***a*** = CE+MM *vs* CE+R, ***b*** = CE+MM *vs* CE+CE, ***c*** = CE+VM *vs* CE+R (n = 10). ▼ Change in recovery method following 15mins cycling exercise.

5.19 Interaction between variables

5.19.1 Continuous recovery: Analysis of the continuous recovery data showed that there was a good correlation between BLa and PoF for CE+CE, MM+MM and VM+VM, but a poorer one for R+R (Table 5.10). Additionally, reasonable correlations were evident between DBP and PoF for VM+VM, MM+MM and R+R, but not for CE+CE.

Table 5.10 Correlation coefficient (r^2) between blood lactate, perception of feeling and diastolic blood pressure comparing manual leg massage (MM+MM) and vibratory leg massage (VM+VM) with recumbent cycling exercise (CE+CE) and rest (R+R) (n = 10).

	Blood Lactate / Perception of Feeling	**Diastolic Blood Pressure / Perception of Feeling**
MM+MM (45mins Manual leg Massage)	0.989	0.968
VM+VM (45mins Vibratory leg Massage)	0.889	0.746
CE+CE (45mins Continuous Cycling Exercise)	0.895	0.070
R+R (45mins Rest)	0.718	0.942

5.19.2 Combined recovery: Furthermore, analysis showed that there is a significant interaction between blood lactate clearance and perception of feeling from 3mins post onwards for the combined recovery methods (Table 5.11). Although the highest in BLa did not correspond with the lowest PoF, the trend between the two variables, from 3mins onwards, mirrored one another. No correlation was seen between PoF and DBP for the same time period, indicating that irrespective of the drop in DBP at 20mins post (5mins after the change in recovery method) feeling continued to improve.

Table 5.11 Correlation coefficient (r^2) between Blood lactate and Perception of Feeling; and Perception of Feeling and Diastolic blood pressure for combined recovery (15mins Cycling Exercise + 30mins Manual leg Massage (CE+MM), (15mins Cycling Exercise + 30mins Vibratory leg Massage (CE+VM) and (15mins Cycling Exercise + 30mins Supine Rest (CE+R)) (n = 10).

	Perception of Feeling & Blood Lactate	**Perception of Feeling & Diastolic Blood Pressure**
CE+R (15mins Cycling Exercise + 30mins Supine Rest)	0.87	0.38
CE+MM (15mins Cycling Exercise + 30mins Manual leg Massage)	0.99	0.21
CE+VM (15mins Cycling Exercise + 30mins Vibratory leg Massage)	0.97	0.23

DISCUSSION

5.20 The Wingate Anaerobic Test

For the investigation, the Wingate Anaerobic Test (WAnT) was adopted for the short bout of maximum intensity exercise. A force of 7.5% body weight was chosen to yield high mechanical power and consequently induce fatigue, and also increase blood lactate concentration. The WAnT was also chosen as there is very limited research investigating recovery using leg massage following a single bout of maximal intensity anaerobic exercise. Previous research in the area have generally used multiple bouts of lower intensity exercise interspersed with short periods of massage (Gupta, Goswami, Sadhukhan & Mather, 1996; Hemmings *et al.*, (2000) & Robertson, Watt & Galloway (2004)); rather than a single bout followed by a prolonged period of massage. The protocol used during this present investigation would have greater relevance in sporting context, particularly with sprint athletics, where maximum power is required for a short period, followed by the need to recover quickly, to restore muscle glycogen.

5.21 The effect of massage on blood lactate clearance following anaerobic exercise

5.21.1 The effect of manual and vibratory massage on blood lactate clearance: Previous research has suggested that the highest lactate occurs between 2 - 10mins following the WAnT (Stainsby, 1986). In this investigation, the highest lactate was measured at 3mins.

During continuous recovery, blood lactate concentration decreased more rapid during manual massage (MM+MM) and vibratory massage (VM+VM), when compared to supine rest (R+R). These data accord with the findings of Bale & James (1993) and Jones & Cotterell (1999), but contradict several studies that together suggest very little difference between rest and massage at decreasing BLa concentration (Hemmings *et al.*, 2000 and Robertson *et al.*, 2004). For combined recovery (CE+MM and CE+VM), combining cycling exercise in the first 15mins of recovery followed by 30mins massage was only marginally more effective than continuous massage alone. It is apparent that vibratory massage (VM+VM and CE+VM) was as effective as manual massage (MM+MM and CE+MM) at decreasing blood lactate concentration following intense exercise, during both combined and continuous recovery. It may therefore be reasonable to conclude that recovery was effected by the massage intervention itself, and this was more important than the type of massage administered, manual or vibratory.

The mechanism by which vibratory massage enhances lactate clearance is unclear; however, it is speculated that in may be the same as with manual massage, which is detailed below. Kerschan-Schindl *et al.*, (2001) showed an increase in limb blood flow measured at the popliteal artery, and an increase in muscle blood volume in the calf and thigh following a bout of vibratory stimulation. Furthermore, Cafarelli, Sim, Carolan & Liebesman (1990) report that vibratory massage increased blood flow within the limb, and stated that this was due to vibratory massage actively contracting the treated muscle.

A comparison of similar studies (Table 1.5) indicates that the time period of massage during this present investigation (45mins) was longer. It is unclear whether such a protracted time period of massage (used in this present investigation) would enhance lactate clearance compared to Rest.

The general sequence and timing of manual and vibratory massage can be seen in Table 5.3. The gluteus maximus contributes considerable force during a revolution of the pedals (Figure 5.13), equal or greater than that of the quadriceps, hamstrings and calf (Faria & Cavanagh, 1978). Therefore, it may have been pertinent to include the gluteus region and lower back into the general massage sequence. However, this raises two questions, the first of practicality and the second of ethical procedures. Firstly, if the gluteus maximus were to receive massage therapy, it would shorten the duration of massage to other muscles, with no guarantee of further enhancing short term recovery. Secondly, for some subjects, having the gluteus region massaged is an invasive procedure, compromising modesty and may diminish the feeling of relaxation. Furthermore, it is unclear whether this altered massage regimen to a greater surface area would decrease lactate concentration.

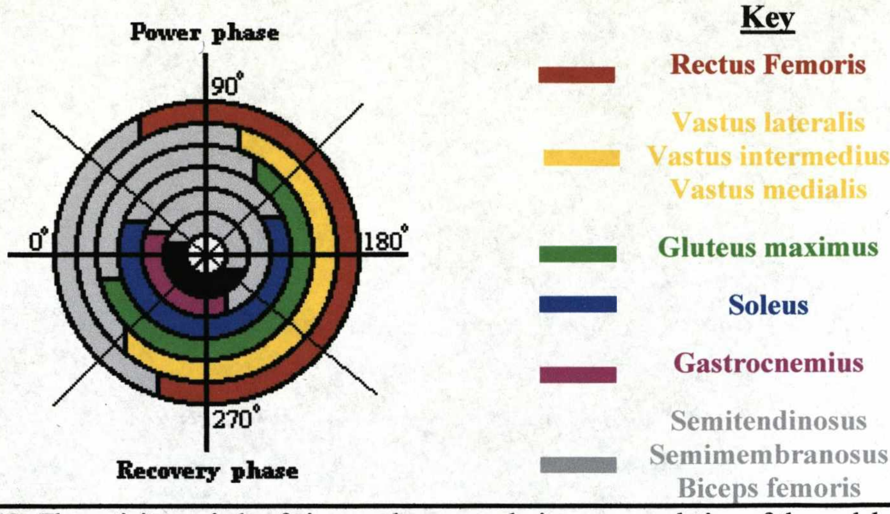


Figure 5.13 The activity periods of six muscle groups during one revolution of the pedals during a Wingate Anaerobic Test (Reproduced from Faria & Cavanagh, 1978).

5.21.2 The effect of Rest on lactate clearance: Continuous and combined Rest (R+R and CE+R) was a less effective method of blood lactate concentration decrease compared to manual/vibratory massage and cycling exercise; and by 45mins post WAnT BLa remained at 6.7±1.1mmol $\cdot$ l^{-1}. On combining 15mins of CE with 30mins of R (CE+R) at 45mins post exercise, BLa was significantly lower (p=0.008) than during continuous Rest recovery (R+R). This was 4mmol $\cdot$ l^{-1} above baseline, indicting that the combination was only marginally more effective. These BLa data are in agreement with Hussain, Smith, Medbak, Wood & Whipp (1996) who investigated the effect of supine rest on humoral variables, limb blood flow and blood pressure for 60mins after the WAnT (Figure 2.32); and at 30mins BLa remained high at 8.4±0.7mmol $\cdot$ l^{-1}; and had only decreased to 4.3±0.8mmol $\cdot$ l^{-1} at 60mins. Estimated total lactate clearance time extrapolated from the data presented by Hussain, Smith, Medbak, Wood & Whipp (1996) was 72mins, which is in agreement with the estimated total clearance time of 70mins seen during the present investigation. Thus, this shows good accordance with previous literature.

During Rest recovery in this present investigation, subjects were required to adopt a prone, followed by a supine position. This was in order to simulate the position adopted during massage; and also to reduce the likelihood of subjects feeling nauseous, light headed and lethargic. During the preliminary study by Jones & Cotterell (1999), four subjects were requested to sit for 30mins following the WAnT; with all subjects reporting feeling unwell, and two of these were physically sick. The 30min lactate concentration during the preliminary study was 7.33±0.43 mmol · l^{-1}; and therefore is in close agreement with the 30min BLa value in the present study (Investigation 4) of 7.23±0.5 mmol · l^{-1}. This is in agreement with Bulbulian, Darabos & Nauta (1987). Therefore, it appears that lactate clearance is not significantly influenced by body position, and the light headedness and nausea are related more to diastolic hypotension than high concentration of circulating lactate (Piepoli *et al.*, 1993).

5.21.3 The effect of cycling exercise on blood lactate clearance: Since the original proposition of superior removal of lactate by Jervell (1928), it has been established that light continuous exercise between 29.7 – 45.3%VO_{2max} (~50 – 60 %HR_{max}) will induce sufficient limb blood flow to decrease the lactate from muscular intercellular compartments and arterialised blood (Belcastro & Bonen, 1975).

Recumbent cycling was selected to simulate a similar position adopted during manual leg massage, vibratory leg massage and rest. It is clear from the data that the recumbent cycling exercise made a significant difference as lactate clearance was enhanced. In addition, considerable diastolic undershoot was avoided by preventing blood pooling, and perception of feeling did improve. This was the most successful method of recovery in the present study, with an estimated clearance time to baseline of 46mins.

Although this investigation was not designed to investigate the biochemical mechanism or mechanisms responsible for the decrease in blood lactate observed following a period of MM or VM, when compared to Rest alone, there are a number of possible mechanisms. Changes in plasma lactate concentrations observed in the present study would be expected to result from:-

1. a massage induced decrease in lactate efflux from the muscles,
2. an increase in direct lactate metabolism by muscle (presumably via the lactate shuttling mechanism), or
3. a decrease in lactate production due to reduced reliance on anaerobic metabolism in the recovery period.

It seems reasonable to speculate that a possible mechanism would involve a temperature dependent process as skin temperature increased by 7.9% (MM) and 9.6% (VM); and aural temperature increased by 1.0% (MM) and 1.6% (VM). A temperature induced decrease in lactate efflux from muscle, would lead to a corresponding decrease in plasma lactate levels when compared to Rest.

In respect of the later, the release of lactate from isolated perfused frog muscle, when subjected to variation in pH and temperature has been studied in detail (Vezzoli, Gussoni, Greco & Zetta, 2003). The results of this study strongly suggested that lactate efflux was primarily dependent on the pH of the perfusing media but the possible effects of temperature remained unclear. Other authors have noted that pH appears to be the most dominant factor effecting lactate efflux in rat skeletal muscle this respect (Roth & Brooks, 1990), although there was a suggestion that the carrier mediated transport of lactate into muscle cells demonstrates increased sensitivity at normal physiological temperature when compared to 25°C. Plasma pH was not measured directly in the present investigation but it seems reasonable to suggest that, based on the results of these animal studies, increased skin/muscle temperature evident during massage may elicit some response in terms of increased sensitivity of muscle cell carriers to lactate uptake.

The lactate shuttle hypothesis as proposed by Brooks (1975), Brooks (1986), Brooks, Dubouchaud, Brown, Sicurello & Butz (1999) and Brooks (2000) is still an area of active debate. The hypothesis postulates that lactate produced within type IIB fibres during intense exercise, and subsequently released into the interstitium, is then taken up and oxidised by slow oxidative type I fibres due to the action of a shuttle system found in the membranes of these fibres. Increase in lactate shuttling and subsequent use of lactate by type one fibres would be consistent with an increase in aerobic metabolism by these fibres and thus an increase in oxygen uptake and decrease in CO_2 output into venous circulate. It has been noted that during the present investigation there was a slight increase in CO_2 production (4.38% MM and 4.49% VM higher) along with increased oxygen consumption following massage when compared to Rest which may reflect such a process.

A final mechanism which may result in lowered plasma lactate concentration in the post-exercise period under both manual and vibratory massage conditions is a decreased reliance on anaerobic metabolism. Although an absolute mechanism for this has not been postulated, several studies indicate that muscle temperature may be a contributing factor. An increase in skin temperature during massage was observed in this study and this appears to be consistent with the previous findings of Durst *et al.*, (2002) who also observed a concomitant rise in muscle temperature following manual massage. In contrast, studies on cooled muscle metabolism have shown that a decrease in skin/muscle temperature has a direct negative effect on oxygen uptake by the muscles which was consistent with increased vasoconstriction (Beelen & Sargeant, 1991). Interestingly this study also indicated a temperature dependent increase in blood lactate concentration as the muscle was cooled. The authors concluded that this response was due to increased anaerobic metabolism, caused by vasoconstriction to the active muscle, thus limiting oxygen availability.

In the present study a seemingly opposite response was noted; following the WAnT there was considerable and sustained vasodilatation (deemed from the decrease in diastolic blood pressure; Figure 5.8a & 5.8b), increased leg skin temperature (Table 5.4 & 5.5). In addition, it has not escaped our notice that there is an a slight increase in oxygen uptake (5.86% MM and 5.65% VM higher) during the recovery period when compared to Rest alone (Figure 5.9a & 5.9b). Whilst this increase may not be statistically significant, it is relatively consistent throughout the entire recovery period and may be indicative of increased aerobic metabolism. All of which may have led to a net decrease in blood lactate concentration (Figure 5.3a & 5.3b). Thus, the increase in temperature and presumably blood flow observed following both MM and VM in the present study may have an indirect effect on plasma lactate concentration as a result of greater oxygen uptake by the recovering muscle, thus reducing the dependency on anaerobic metabolism. Whether this effect alone is sufficient to account for the entire decrease in plasma lactate observed in the present study remains to be elucidated.

5.22 The effect of massage on heart rate, blood pressure and rate pressure product following anaerobic exercise

5.22.1 The effect of leg massage on heart rate: Predictably, during recovery, the heart rate for cycling exercise remained elevated due to the submaximal cycling, with subjects controlling their heart rate at the appropriate exercise intensity (~60%HR_{max}) by maintaining cadence and altering resistance.

Despite not reaching significance, the heart rate for manual leg massage and mechanical vibratory leg massage were noticeably lower throughout recovery than that for Rest, indicating a parasympathetic response (Longworth, 1982; Corley, *et al.*, 1995; Labyak & Metzger, 1997; and Delaney *et al.*, 2002). However, this can not be substantiated, as there was no measure of heart rate variability taken during this present investigation; although the data presented in Investigation 1, 2 and 3 confirms that massage does indeed increase parasympathetic drive. The same trend occurred in heart rate during the pilot study in Appendix 2. The present data supports work by Barr & Taslitz (1970); Longworth (1982) who reported a decrease in HR during and following massage, compared to Rest. The aforementioned investigations by Barr & Taslitz (1970) and Longworth (1982) measured heart rate after a period of inactivity and not a bout of strenuous exercise. Gupta, Goswami, Sadhukhan & Mather (1996) compared heart rate during manual massage and rest following 3, 5, and 15secs supramaximal bouts; with no significant differences seen between the two conditions.

5.22.2 The effect of leg massage on blood pressure: Blood pressure was measured during the present studies, and gave a greater insight into the effect of massage following intense exercise. Other similar studies have not reported on blood pressure responses (Martin *et al.*, 1998; Hemmings *et al.*, 2000; Monedero & Donne, 2000; and Robertson, Watt & Galloway, 2004) and as such, the effect of massage on blood pressure following a bout of intense exercise has so far been unclear. Following the WAnT, cardiac output declines from the high exercising level, more rapidly than systemic vascular resistance recovers, causing an imbalance resulting in sustained diastolic hypotension (Coats *et al.*, 1989 and Haliwell, 2001). This response is predominantly humoral caused by the increase in lactic acid, PO_2, adenosine & sodium; and decrease in pH, PCO_2, bicarbonate & potassium (Hussain, Smith, Medbak, Wood & Whipp, 1996); and causes a decrease in vascular resistance, thus causing sustained diastolic hypotension.

For manual leg massage, mechanical vibratory leg massage and Rest, the supramaximal exercise bout caused considerable and sustained diastolic blood pressure undershoot. The post WAnT hypotension was lowest at 3mins post, which coincided with the highest blood lactate measurement, and also the lowest perception of feeling. DBP demonstrated a gradual increase had returned to near normal at 45mins during continuous recovery protocol, a trend also reported by Hussain, Smith, Medbak, Wood & Whipp (1996).

During cycling exercise (CE+CE) DBP remained relatively constant throughout the recovery period. This indicates that the mechanical action of the exercise bout was sufficient to maintain vascular resistance, and therefore avert any undershoot, and consequently prevent any light headedness or nausea. Conversely during combined recovery, combining MM, VM or R with 15mins CE, did not prevent DBP decreasing significantly compared to cycling exercise alone; as DBP decreased following the change in recovery mode. Therefore, the cycling exercise temporarily averted any peripheral vasodilatation by maintaining venous return through rhythmic muscle contraction, despite a high RER (indicating metabolic acidosis) and elevated BLa concentration.

5.22.3 The effect of leg massage on rate pressure product: Rate pressure product is the surrogate measure of myocardial oxygen uptake and cardiac workload (Herminda *et al.*, 2001) and could be considered a surrogate indication of sympathovagal balance. RPP was seen to be significantly lower during manual and vibratory massage than Rest.

In conclusion, continuous leg massage had no greater effect than Rest at preventing diastolic hypotension. Furthermore, by combining cycling exercise with R, MM or VM, this not prevent DBP undershoot upon the change in recovery mode. In addition, the results indicate that massage has a parasympathetic effect, decreasing HR and RPP during recovery from the WAnT.

5.23 The effect of massage on oxygen uptake and carbon dioxide output following anaerobic exercise

5.23.1 The effect of leg massage on metabolic rate: The highest values in VO_2 of 45.9±8.9ml O_2 kg^{-1} were recorded immediately at the end of the WAnT. For CE, subjects maintained a steady cadence and altered resistance to maintain a constant intensity (60%HR_{max}) during recovery, and therefore VO_2 remained relatively constant throughout.

VO_2 for manual leg massage, mechanical vibratory leg massage and Rest were all identical in nature, immediately rising on completion of the WAnT and then decreasing towards baseline during the remaining recovery time. This slow decrease in oxygen uptake can be accounted for by the slow and fast components of excess post exercise uptake (EPOC), catabolising lactic acid and replenishing ATP, phosphocreatine, and glycogen; and is a direct consequence of such a physically demanding test (Bahr *et al.*, 1992). Measurements were taken until the end of the recovery period of 45mins post WAnT, and not until the values returned to baseline, therefore it is not possible to speculate how long the EPOC effect would continue in the present investigation.

In this present investigation, VO_2 for manual leg massage (MM+MM & CE+MM) and mechanical vibratory leg massage (VM+VM & CE+VM) was slightly higher, but not significantly so, than the values for Rest (R+R & CE+R) throughout the 45min recovery period. Gupta, Goswami, Sadhukhan & Mather (1996) report a similar effect, showing an increase in VO_2 for massage when compared with rest, during recovery from a bout of supramaximal exercise (Figure 5.14a and 5.14b). They attributed the slight increase in VO_2 to the friction between the hand and treated skin, consequently raising skin temperature, which may then increase muscle temperature. Although the effect of massage on oxygen uptake has been reported, the effect of the limb and muscle temperature increase caused by the fictions of massage (on oxygen uptake) has yet to be elucidated. This VO_2 temperature dependent response has been reported previously under resting conditions, but not during massage therapy. Beelen & Sargent (1991) reported that a decrease in temperature from 37.1±0.3°C to 33.0±1.3°C (measured at the vastus lateralis), caused a decrease in VO_2 from 370±60ml · min^{-1} to 350±40ml · min^{-1} respectively.

Conversely, Koga, Shiojiri, Kondo & Barstow (1997) reported that resting VO_2 values at 38.9°C (381±102ml · min^{-1}) were higher than oxygen uptake at 35.3±0.4°C (355±71ml · min^{-1}). Although the leg massage administered by Gupta, Goswami, Sadhukhan & Mathur (1996) may not have increased the vastus lateralis muscle temperature to the same degree as the values reported by Koga *et al.*, (1997), their results may indicate that the effect on VO_2 (by massage) was a temperature dependent response, caused by an increase in limb skin, muscle and blood temperature.

The skin hyperaemia observed during both manual and vibratory massage in this investigation, as a result of effleurage and petrissage, resulted in an increase in Leg_{Temp}, and also a higher $Aural_{Temp}$ compared to Rest. No measure of intra-muscle temperature was made in the present study; however, data from Drust *et al.*, (2003) suggests a temperature increase within the vastus lateralis following 10mins of massage. Therefore, it is postulated that the slight augmentation in VO_2 may reflect a slight temperature dependent alteration in oxygen uptake occurred during the present investigation where limb skin temperature increased, and was not matched by a significant (but insignificant) increase in oxygen uptake. This may also tally with the mechanism proposed for the decrease in lactate concentration, caused by an increase in aerobic metabolism by skeletal muscle fibres.

A VCO_2 and RER overshoot was observed following the WAnT, reflecting considerable metabolic acidosis during the early part of the recovery phase for all conditions. This is corroborated by the increase in blood lactate. The overshoot continued until 10mins post WAnT when the RER decreased to below 1. Similar to the trend in oxygen uptake, VCO_2 for manual leg massage (MM+MM & CE+MM) and mechanical vibratory leg massage (VM+VM & CE+VM) was slightly higher, but not significantly so, than the values for Rest (R, R+R & CE+R) throughout the 45mins recovery period. Gupta, Goswami, Sadhukhan & Mather (1996) report a similar effect (Figure 5.14a & 5.14b).

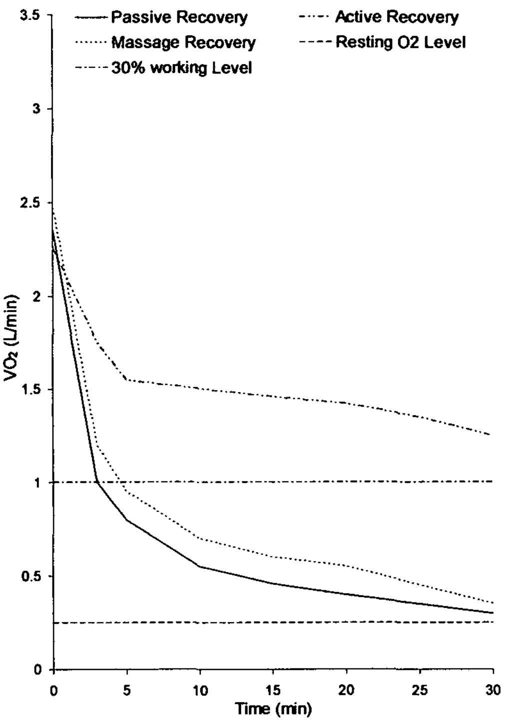


Figure 5.14a Changes in oxygen uptake following various modes of recovery (n=10) (Data from Gupta, Goswami, Sadhukhan & Mather (1996).

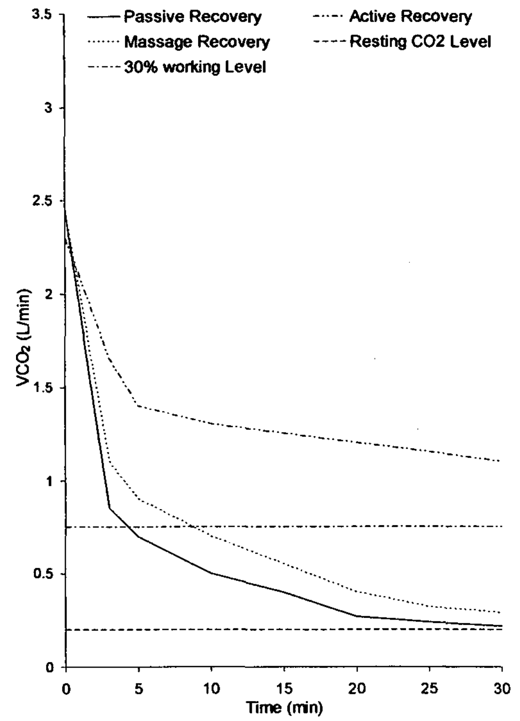


Figure 5.14b Changes in carbon dioxide production following various modes of recovery (n=10) (Data from Gupta, Goswami, Sadhukhan & Mather (1996).

5.23.2 The effect of leg massage on pulmonary ventilation: Despite not affecting the constituents of metabolic rate, the massage conditions did have an effect on pulmonary variables, which would give an indication of autonomic relaxation. This is the first study to report the effect of massage on the constituents of PV following exercise. During Investigation 5 there was no significant difference in ventilation *per se*; however, there was a significant difference in the contributors of ventilation. The results in indicated that respiratory rate for MM was also significantly lower (7.6%) than R, as was VM (1.7%). In addition to this decrease in respiratory rate, there was a concomitant increase in tidal volume. However, this increase in V_T offset the decrease in RR, and therefore did not cause a significant alteration in pulmonary ventilation. The mechanism for this change in RR and V_T is presented in section 3.30

5.24 The effect of massage on aural and leg skin temperature following anaerobic exercise

$Aural_{Temp}$ for manual leg massage and vibratory massage was not significantly different from each other during both combined and continuous recovery. It was not feasible to measure intra-muscle temperature, only skin and aural temperature. The range of leg skin temperatures were similar to values previously reported (Gregson, Drust, Batterham & Cable, 2002; and Drust *et al*,. 2003; and Hinds *et al.*, 2004). Drust *et al.*, (2003) measured leg skin temperature and leg intra-muscle (vastus lateralis) temperature at a depth of 1.5, 2.5 and 3.5cm during and following massage. Massage was applied to the thigh for a similar time period used within the present investigation. They reported an elevation in the thigh skin temperature of approximately 2°C, up from a baseline of 31.5°C which is consistent with this investigation. Leg muscle temperature was not measured in the present investigation, however it is expected that as the massage time period and type of massage was similar to that of the study by Drust *et al.*, (2003), where vastus lateralis temperature increased by approximately 1°C at 3.5cm depth and 3°C at 1.5cm depth.

There is currently no research data reporting limb or muscle temperature changes during vibratory leg massage following exercise. In the present study, vibratory leg massage was applied to the legs during both continuous and combined recovery. Leg_{Temp} increased by 2.5±0.9°C for VM+VM and 2.9±0.8°C for CE+VM; which presumably occurred due to the greater friction between the G5® adaptors and treated skin. It is unclear whether this enhanced response by VM would have heated the underlying muscle at a deeper level; or whether the response was merely localised hyperaemia of the treated skin due to friction.

5.25 The effect of massage on perception of feeling following anaerobic exercise

In addition to the positive physiological effects seen during manual leg massage, the results for perception of feeling indicated that manual massage also had a significantly greater psychological effect during recovery than vibratory massage, Rest, or cycling exercise. For MM+MM and CE+MM for continuous and combined recovery, subjects registered a PoF of 'Very Good' at the end of the recovery period. In this present investigation, perceived recovery was reasonably related to lactate kinetics, with a significant correlation evident between BLa concentration and perception of feeling, for each of the conditions. Hemmings *et al.*, (2000) also report a positive psychological effect during massage following multiple bouts of high intensity boxing; however, they report that lactate clearance was not positively affected by the arm massage.

During Rest, subjects reported feeling nauseous, light headed and lethargic. This could account for the PoF remaining lower than the other conditions. By the end of recovery PoF had not returned to the baseline of +6 (Very Good) and remained at +2 (Fairly Good). It is postulated that the low PoF was due to a combination of the high lactate concentration, elevated heart rate and diastolic undershoot, indicating a greater sympathetic effect caused by elevated adrenaline and nor adrenaline.

CONCLUSIONS

5.26 Conclusions

In conclusion, following bout of anaerobic exercise, continuous 45mins MM+MM and VM+VM were equally effective at decreasing lactate concentration, possibly due to either a decrease in efflux from the muscles, increase in direct lactate metabolism by muscle or a reduced reliance on anaerobic metabolism in the recovery period. This enhancement is contrary to several studies who have reported no effect. There was also an enhanced the feeling of relaxation and wellbeing during recovery, scoring higher than the other conditions (Rest and Cycling Exercise). Therefore, the positive psychological effect of manual massage and to a lesser extent vibratory massage during recovery is linked to, but cannot be attributed entirely to, decreased lactate concentration.

For combined recovery (CE+MM and CE+VM), combining cycling exercise in the first 15mins of recovery followed by 30mins massage was only marginally more effective than continuous massage alone at decreasing lactate concentration; and did not prevent sustained peripheral vasodilatation following the change in recovery mode at 15mins post WAnT.

The data of the current investigation suggests that massage is an effective method of recovery from intense anaerobic exercise, and as both massage interventions are equally as effective it may be reasonable to conclude that recovery was affected by the massage intervention itself, and this was more important than the type of massage administered, manual or vibratory.

CHAPTER 6

The effect of an arm massage following a bout of eccentric exercise

(Investigation 5)

INTRODUCTION

"The primitive instinct which promotes both man and the lower animals to rub and press any part where discomfort is felt, has as its motive the alleviation of uneasiness. It is a definite response to a definite stimulus" Cuthbertson (1933)

6.1 Overview

Slowly lowering a heavy weight held in the hand involves an eccentric action of the biceps muscle. During the eccentric action, damage may occur due to the nature of the action. As the muscle contracts, it is stretched which can result in muscle damage and resultant pain.

The discomfort sensation experienced within skeletal muscle following unaccustomed physical activity occurs not only in untrained individuals but also in elite athletes, indicating that a high level of fitness offers no protection. This phenomenon is referred to as delayed onset of muscle soreness (DOMS) and occurs following any unaccustomed high intensity exercise such as downhill running and eccentric weight training (Smith *et al.*, 1994).

6.2 Strategies and treatments for counteracting the negative effect following eccentric exercise

A number of strategies and treatments have been proposed to counteract the negative effects of acute muscle injury, which disrupts not only athletic training and performance, but also everyday activities (Smith *et al.*, 1994) (Figure 6.1). These include warm-up, stretching pre and post exercise (Wiktorsson-Möller, Öberg, Ekstrand & Gillquist, 1983; High, Howley & Franks, 1989 and Rahmani-Nia, Rahnama & Ebrahim, 2004), ultrasound (Craig, Bradley, Walsh, Baxter & Allen, 1999), aspirin and non-steroidal anti-inflammatory drugs (Donnelly, McCormick, Maughan, Whiting & Clarkson, 1988; and Hasson *et al.*, (1993)), Vitamin C (Saxton, Donnelly & Roper, 1994), cryotherapy (Eston & Peters, 1999) and transcutaneous electrical nerve stimulation (Mobily, Herr & Nicholson, 1994). None have proved conclusive.

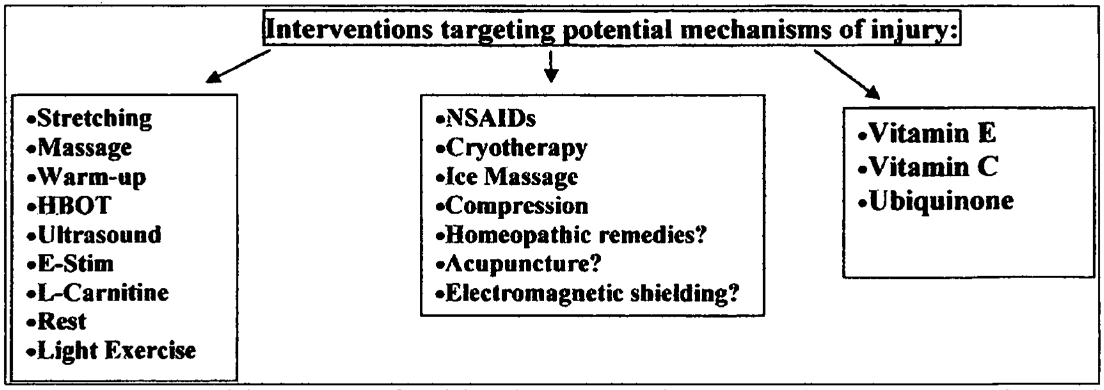


Figure 6.1 Potential treatments for delayed onset muscle soreness (From Connolly, Sayers & McHugh, 2003).

The increased metabolic rate (Dolezal, Potteiger, Jacobsen & Benedict, 2000), stiffness, tenderness, pain and swelling (Hemmings, 2001); and decreased range of motion and force production (Kuipers, 1994) associated with DOMS, usually appears between 8hrs and 24hrs post exercise (Smith *et al.*, 1994), peaking at approximately 48hrs (Weber, Servedio & Woodall, 1994) and then reduces over subsequent days. This time pattern of soreness can remain for up to 2wks following repeated high force eccentric contractions (Newham, Jones and Clarkson, 1987), and the muscle damage may take up to 12wks to fully repair (Evans, 1987). Hemmings (2001) also suggests that all aforementioned signs and symptoms of DOMS may predispose an athlete to the risk of future sporting injury.

Although several theories have been suggested regarding the possible cause of DOMS, there has been no consensus. However, it is thought that DOMS is caused by myofibril damage, common to the Z-band, with connective tissue damage at the myotendinous junction also occurring (Smith *et al*, 1994). Several other events caused by the exercise induced stress compromise the skeletal muscles' mechanical strength:-

- Alterations occur to the muscle sarcolemma (Byrd, 1992) which in turn leads to an alteration in muscle cell calcium. This damage to the sarcoplasmic reticulum increases intracellular calpain (Armstrong, 1990).
- Limb swelling associated with tissue damage occurs due to the fluid passing to the site of injury, causing acute oedema via damage to the capillary endothelium.

Despite all these effects, it is still not clear why pain occurs, and why this is delayed following these bouts of unaccustomed exercise (Ernst, 1998).

The pain sensation experienced is replicated by an increase in indicators of cell membrane damage. The indicators commonly used to indicate skeletal muscle damage following EE are lactate dehydrogenase, neutrophils, TNF-alpha, Heat shock protein 70, interleukin-70 and creatine kinase (CK) (Nosaka & Clarkson, 1996a; Nosaka & Clarkson, 1996b). The latter of these (CK) is commonly used because of its relative low cost and ease of use (Lee & Clarkson, 2003), and therefore has been used in this present investigation.

For this investigation, the EE bout was a modified preacher curl performed on an incline bench which enabled the arm to extend from 50° to 170°. The loading was set at 80% of each subject's one repetition maximum, and they completed three sets of 10 repetitions using their non dominant arm. Previous research has used this method successfully to augment CK levels, increase limb circumference, and cause perceived muscle pain (Clarkson, Nosaka & Braun, 1992; Nosaka & Clarkson, 1996; and Lee & Clarkson, 2003).

6.3 The effect of manual and vibratory massage on recovery following exercise

As manual massage is routinely used to aid recovery following vigorous exercise (Balke, Anthony & Wyatt, 1989), it has been postulated that the combined increase of circulation and lymph flow, in addition to decreased muscle tension, would in some way ameliorate the painful effects of acute muscle damage (Cafarelli, Sim, Carolan & Liebesman, 1990; Goats, 1994 and Weber, Servedio & Woodall, 1994). Furthermore, Tiidus (1999) suggests that manual massage administered during the very early stages of muscle injury may decrease pain and reduce localised inflammation.

Vibratory massage is not widely used in this respect, with most data reported in the literature concentrating on its use to alleviate chronic back pain (Lundburg *et el.*, 1984), the alleviation of pain following maximal voluntary muscle contractions (Cafarelli, Sim, Carolan & Liebesman, 1990), and numbing areas in preparation for cosmetic procedures (Smith, Comite, Balasubramanian, Carver & Liu; 2004).

Within these studies, it is reputed that vibratory massage reduces the perceived pain experienced by acute pain sufferers, possibly by closing pain gates (Smith *et al.*, 2004).

A generally accepted hypothesis has been proposed by Melzack & Wall (1965), who suggested that descending and ascending inhibitory pain control can be influenced by 'pain gates' within the spinal cord. These gates are opened with increased activity from the small diameter nerve fibres transmitting pain sensations to the thalamus (Marieb, 2006); and closed by high level of stimulation of the large diameter nerve fibres which inhibit pain (Melzack, 1999). There are significant numbers of large diameter fibres in the skin, therefore vibration stimulation may cause the gate to be set in a more closed position, and thus inhibit the pain sensation association with eccentric exercise (Carlsöö, 1982; Latham, 1985; Sherer, Clelland, O'Sullivan, Doleys & Canan 1986; Horn & Munafò 1997; and Sofaer, 1998).

AIMS

6.4 Aims

There is a lack of consensus regarding the use of massage as a recovery method following acute muscle injury. Furthermore, there is paucity of research investigating the positive effects of vibratory massage on perceived pain. In order to examine the effect of massage on the resultant detrimental physiological and psychological alterations which occur following acute muscle injury; the aim of this investigation was to elucidate the analgesic effect of administering arm massage immediately after a bout of eccentric exercise.

In order to quantitate and monitor recovery, heart rate, blood pressure and blood lactate (BLa) were measured to asses short term recovery; serum creatine kinase (CK) was measured as an indirect gauge of muscle damage; limb circumference (LC) as a marker of oedema; repeated 1 repetition max tests to assess muscle strength; and perception of pain and perception of feeling as subjective measures of mood state. The vibratory and manual massage were administered immediately following the EE bout, which was expected to correspond with the increase in limb circumference and perceived pain; and a decrease in perception of feeling. The duration of the massage was 8mins, which is consistent with the recommendation for the duration of arm massage (Cash, 1999).

SPECIFIC MATERIALS AND METHODS

(Investigation 5)

6.5 Subjects

30 male subjects participated (mean±SD: age 25.1±3.9yrs, weight 75.6±6.8kg and height 177.3±7.4cm) (Table 6.1). All were unaccustomed to eccentric exercise and free from injury to the arm, chest or shoulder. They were requested to refrain from any form of heavy exercise 48hr before, and for five days after the eccentric exercise bout. Subjects were also requested to refrain from consuming alcohol, vitamin supplementation and anti inflammatory drugs. Each subject completed one trial.

Table 6.1 Age, height, weight, 1 repetition maximum and main participation sport of the 30 male subjects participating in Investigation 5.

Subject no.	Age	Weight	Height	1 rep. max.	Recovery group	Main sport
1	28	176.5	74.5	13.5	VM	Hockey
2	22	179	86	17.9	VM	Boxing
3	25	176	87	15.6	R	Swimming
4	25	178	75.5	17.9	MM	Swimming
5	27	177	75	16.0	MM	Triathlon
6	29	172	75	18.8	MM	Football
7	28	189	72	21.1	R	Football
8	18	178	81	17.4	R	Rugby
9	23	173	71	16.1	R	Rugby
10	25	176	68	13.2	VM	Rugby
11	20	181	78	14.7	VM	Football
12	23	177	69	14.3	VM	Swimming
13	22	173	80	16.4	VM	Swimming
14	35	179	84.2	16.9	MM	Football
15	24	169	72	16.1	MM	Swimming
16	25	182	85	20.8	MM	Basketball
17	30	171	81	15.6	MM	Football
18	24	169	69	19.2	R	Running
19	26	172	68	17.9	R	Cycling
20	19	176	70	12.5	VM	Rugby
21	32	186	84	12.5	VM	Basketball
22	22	179.5	72.5	11.9	R	Running
23	26	164	60	18.4	R	Running
24	21	172	70	19.5	MM	Cycling
25	25	167.5	68.5	19.2	VM	Cycling
26	27	188	86	17.9	R	Rugby
27	29	189	79	17.9	R	Basketball
28	20	170	70	16.0	VM	Football
29	29	162	79	17.4	MM	Swimming
30	24	190	80	13.2	MM	Basketball

6.6 Exercise Test

6.6.1 One repetition maximum test (1RM): Subjects attended the laboratory 48hrs prior to being tested. 1RM was assessed in the non dominant arm in a standing position, using an inclined gym bench to support the upper arm, and was determined through trial and error, similar to the method detailed by Hoeger, Hopkins, Barette & Hale (1990). The initial weight was set at 14kg; if the subject was able to complete one repetition with ease the weight was increased by 1kg. As it became more difficult for the subject, the weight was increased by 0.5kg; and nearing maximum was increased by 0.1kg. An interval of two minutes was allowed between each attempt. Subjects were not informed about the weight they were lifting, and were only informed on completion of the investigation. The mean 1 biceps curl repetition max (1RM) was 16.5±2.5kg. During this initial visit, subjects were also familiarised with the eccentric exercise protocol using a weight of approximately 25%1RM.

6.6.2 Warm up: Subjects were required to prepare for the test with a 10min submaximal arm warm-up at 30watts using a Monark Rehab 881E arm ergometer (Monark Bodyguard, Varberg, Sweden).

6.6.3 Eccentric biceps exercise: In a standing position, using an inclined gym bench to support the upper arm, subjects undertook 3 sets of 10 repetitions of eccentric bicep curls (non-dominant arm) at 80% of 1 repetition maximum (RM). Chen (2006) suggests that 80%1RM is an optimal load that is commonly used during a weight training programme by an average person, and therefore was used in this present investigation. The eccentric contraction extended the elbow from 50° to 170°, and took 10secs (Figure 6.2a); assistance was then given with the 2sec concentric phase (Figure 6.2b) (one minute of rest was given between each set). A verbal countdown was given for each repetition to standardise between subjects. During the 2sec concentric phase, assistance was given by a 'spotter' to lift the weight back to the original starting position. On completion of the EE, subjects were randomly assigned to one of three recovery groups.

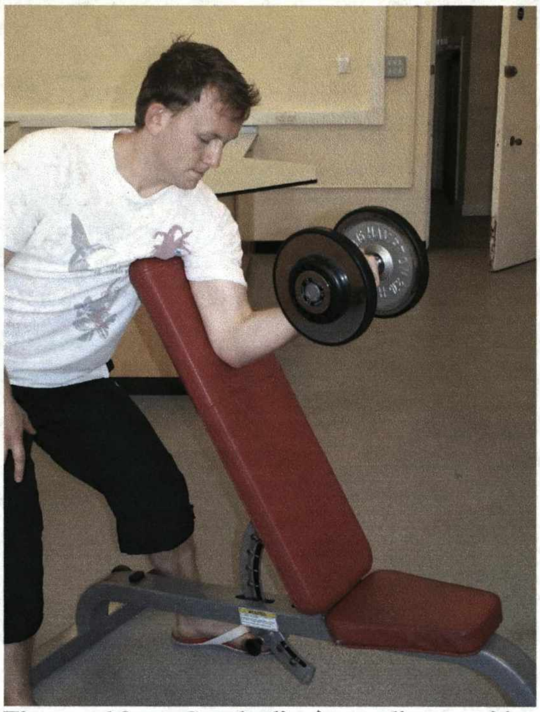


Figure 6.2a Standardised standing position (preacher curl) adopted during the bout of eccentric biceps exercise. The eccentric contraction extended the elbow from 50° to 170°, and lasted 10secs.

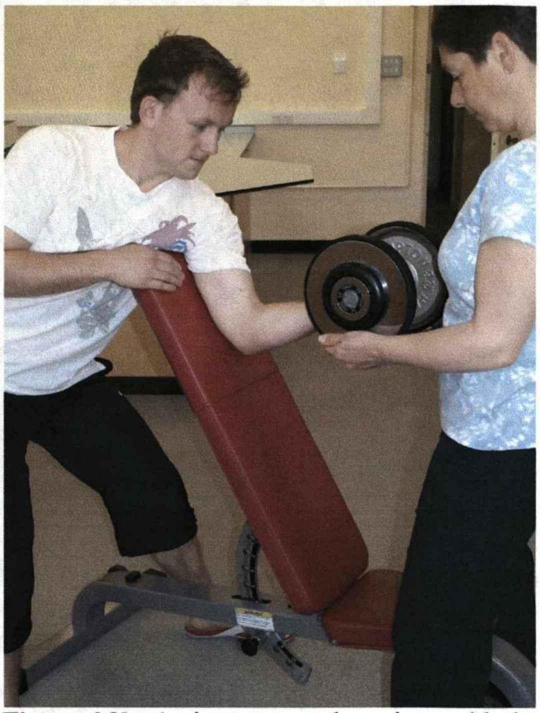


Figure 6.2b Assistance was then given with the 2sec concentric phase.

6.6.4 Rating of Perceived Exertion (RPE): RPE (Borg, 1998) was measured at the end of each set of repetitions during the eccentric exercise bout.

6.7 Recovery Protocols

6.7.1 Manual arm massage (MM): During the 8min manual massage the subject was seated with lower arm supported on a therapy couch similar to Figure 6.3 & 6.4. The general sequence of massage (manual and vibratory) is detailed in Table 6.2.

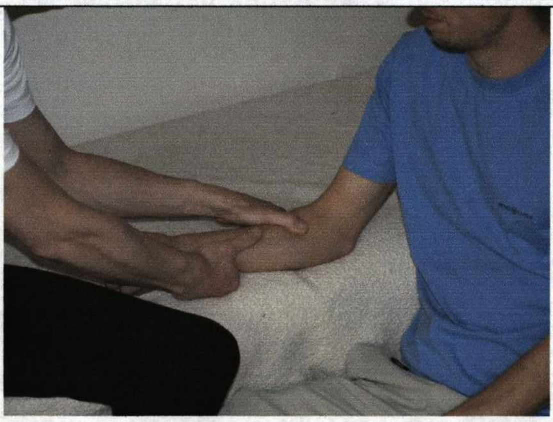


Figure 6.3 Effleurage of the forearm extensors with the arm supported on a therapy couch

Figure 6.4 Petrissage of the triceps

6.7.2 Vibratory arm massage (VM): The 8min vibratory arm massage was administered at 60Hz using the round sponge (app. 210) to simulate effleurage, and 2-ball adaptor (app. 223) to simulate petrissage.

Table 6.2 General sequence of arm massage (manual and vibratory) (total time = 8mins).

General sequence	Time (mins)
Superficial effleurage of whole arm	1
Superficial effleurage of biceps	0.5
Superficial effleurage of triceps	0.5
Deep effleurage of biceps & triceps	1
Petrissage of biceps & triceps	1
Superficial effleurage of forearm	1
Deep effleurage of forearm	1
Deep effleurage of whole arm	1
Superficial effleurage of whole arm	1

6.7.3 Rest (R): Subjects were required to sit and rest for 8mins, with the lower arm supported on a therapy couch.

6.8 Data collection

The protocols for rating of perceived exertion, heart rate, blood pressure, rate pressure product, blood lactate, and perception of feeling are detailed in Chapter 2. Specific methods used during this investigation were:-

6.8.1 Creatine Kinase (CK): Creatine kinase was used as an indirect measure of muscle damage. 32μl finger prick whole capillary blood from a warmed clean dry finger was analysed enzymatically at 37°C via colourometric assay, using a Reflotron® (Roche Diagnostics, Mannheim, Germany). The Reflotron® system utilises plasma separation which is integrated within the test strip (Eston, Finney, Baker & Baltzopoulos, 1996).

6.8.2 Limb circumference (LC): LC was used as a marker of oedema, and measured at two sites on the arm by an experienced technician using a non-stretch flexible tape and marked with a permanent pen (Figure 6.5). The two sites were measured 3cm above and below the crease of the elbow (approximate location of the myotendinous junction) with the arm hanging by the side of the body. In accordance with the recommendations by Nosaka, Newton & Sacco (2002), a mean was then taken from the two measurement sites.

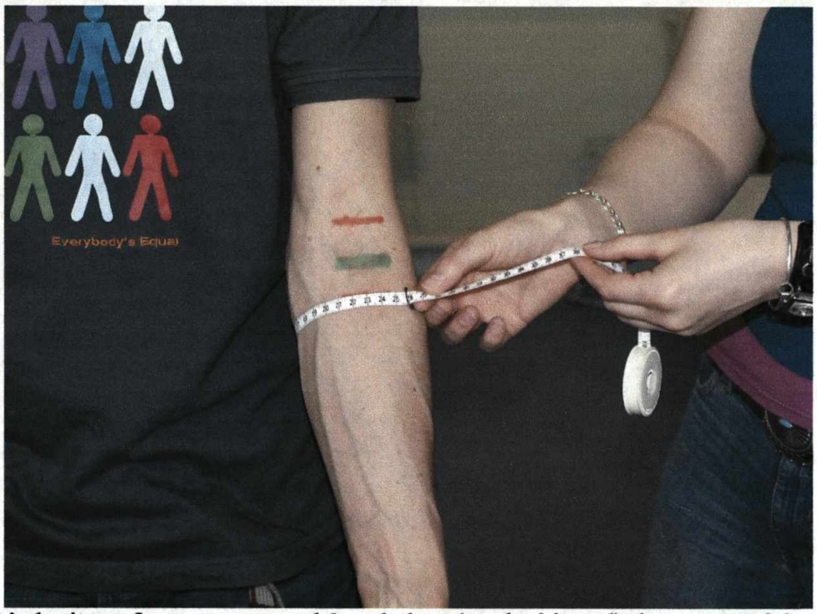


Figure 6.5 Limb circumference measured 3cm below (marked in red) the crease of the elbow (green line) by an experienced technician using a non-stretch flexible tape and marked with a permanent pen.

6.8.3 Muscle strength (MS): The 1RM protocol was used; however, the initial weight was 60%1RM, which allowed for the anticipated decrease in muscle strength.

6.8.4 Perceived Pain: A 7 point scale was used as a subjective assessment of pain (0=No Pain; 6=Unbearably Painful). At each measurement timepoint, subjects were requested to flex and extend the elbow; and requested to palpate their biceps brachii, brachioradialis and forearm extensors before recording the result.

6.9 Timeline of measurements

Table 6.3 illustrates which measurements were taken, and when.

Table 6.3 Measurements taken at each time point

	RPE	HR	BP	RPP	BLa	CK	Limb circ.	Muscle strength	Perception of Pain	Perception of Feeling
Baseline	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
During EE	✓									✓
Post EE		✓	✓	✓	✓	✓	✓		✓	✓
Recovery		✓	✓	✓	✓	✓	✓	✓	✓	✓
4hrs									✓	
8hrs									✓	
24hrs						✓	✓	✓	✓	✓
48hrs						✓	✓	✓	✓	✓
72hrs						✓	✓	✓	✓	✓
96hrs						✓	✓	✓	✓	✓
120hrs						✓	✓	✓	✓	✓

6.10 Statistical analysis

6.10.1 Parametric data are presented as Mean ± Standard deviation, and analysed using a One-way ANOVA test. *Post hoc* independent samples *t*-test analysis was used to compare effects between conditions; and paired *t*-test analysis was also used to compare post treatment to baseline. Non-parametric data are presented as Median ± InterQuartile Range, and analysed with the Kruskal-Wallis test and *post hoc* with a Mann Whitney U test in order to compare effects between conditions. Wilcoxon's signed-rank test was also used to compare post treatment to baseline. For correlation analysis, bivariate Pearson's correlation coefficient was calculated. The level of significance was taken as $p<0.05$.

RESULTS

6.11 Rating of Perceived Exertion during a bout of eccentric exercise

A rating of perceived exertion (RPE) scale was used to gauge the intensity of the EE bout. RPE was taken at the end of each set of 10 repetitions. On completion of the first set, RPE increased from the baseline measurement of 6 (No exertion at all) to 13 (IQR 12, 15) (Somewhat hard). Subject's registered 15 (IQR 14, 17) (Hard (heavy)) at the end of the second set of 10 repetitions; and 19 (IQR 19, 20) (Extremely Hard) on completion of the exercise bout (Figure 6.6). The final RPE indicated that the subjects were near exhaustion from the EE, and therefore the EE was deemed as successful at causing muscular fatigue.

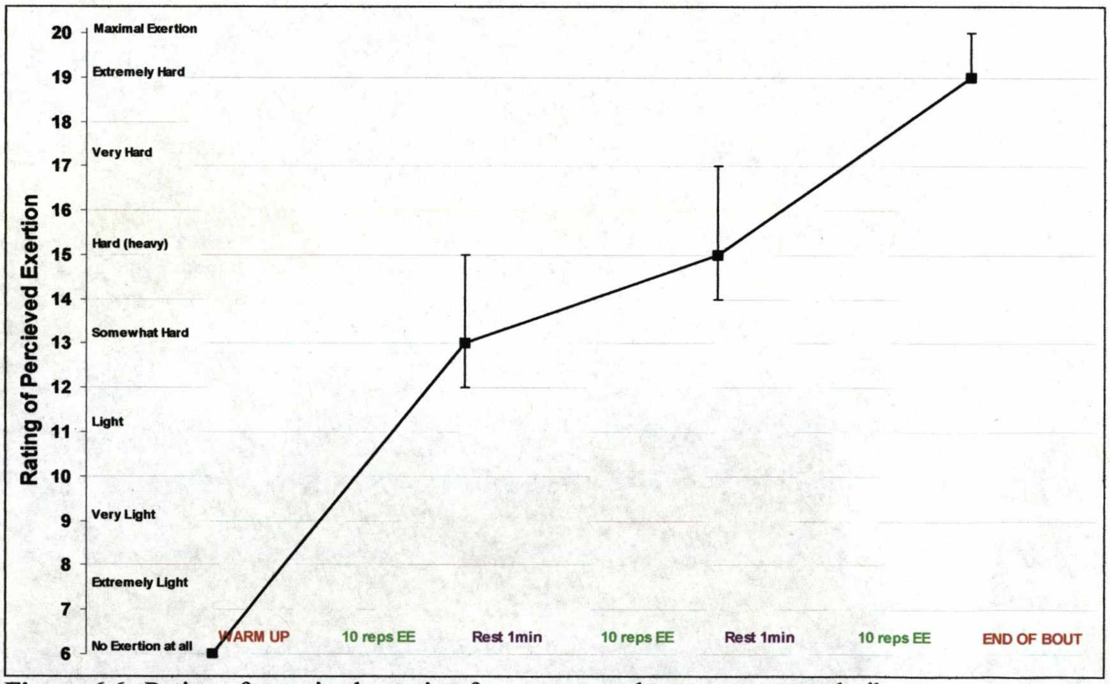


Figure 6.6 Rating of perceived exertion for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise ($n = 30$).

6.12 The effects of massage on heart rate, blood pressure and rate pressure product

All cardiovascular variables increased during the eccentric exercise bout, due to its strenuous demands (Table 6.4). There was no significant difference for HR, BP or RPP following the 8min recovery between the three recovery conditions.

Table 6.4 Heart rate, blood pressure and rate pressure product response for rest, manual arm massage and vibratory arm massage prior to and following a bout of eccentric exercise (n = 30).

	Baseline	Post EE	Post-R	Post-MM	Post-VM
Heart rate (bpm)	67.3±6.4	121.5±6.7	78.8±6.1	80.1±5.9	78.5±6.4
Systolic blood pressure (mmHg)	117.8±6.3	141.7±8.2	123.1±10.8	119.9±10.5	121.2±9.2
Diastolic blood pressure (mmHg)	76.3±4.1	99.6±7.1	81.2±4.2	79.4±4.5	82.1±3.9
Rate pressure product (units)	7928±417	17217±787	9692±521	9532±554	9499±516

In conclusion, the results indicate that manual or vibratory massage did not have any greater effect on the parasympathetic system, compared to Rest, during recovery from eccentric exercise.

6.13 The effects of massage on blood lactate concentration

Baseline blood lactate concentration was 1.1±0.3mmol · l^{-1} (Table 6.5). There was a significant increase following the eccentric exercise bout, and BLa remained significantly above baseline following the 8min massage. In conclusion, neither VM nor MM significantly reduced BLa concentration post EE.

Table 6.5 Blood lactate concentration for rest, manual arm massage and vibratory arm massage prior to and following a bout of eccentric exercise (n = 30). * Significant difference compare to Baseline (p<0.05).

	Baseline	Post eccentric exercise	Post 8mins recovery
R	1.1±0.3	4.5±0.4*	2.8±0.3*
MM	1.1±0.3	4.2±0.5*	2.6±0.2*
VM	1.1±0.3	4.6±0.5*	2.9±0.3*

6.14 The effect of massage on creatine kinase

From a baseline of 96.5±35.5U/L (Figure 6.7), CK did not rise significantly either immediately post EE, or following the 8min recovery period. However, CK increased to 387.7±153.4U/L, 436.7±99.1U/L and 358.6±121.3U/L for R, VM and MM respectively at 24hrs. The highest values for CK were recorded at 48hrs post EE, 1089.2±232.2U/L (R), 1001.4±168.1U/L (MM) and 1044.4±189.9U/L (VM). The CK level at 120hrs post EE for all conditions remained higher than baseline. Neither manual or vibratory massage had a positive impact on CK concentration.

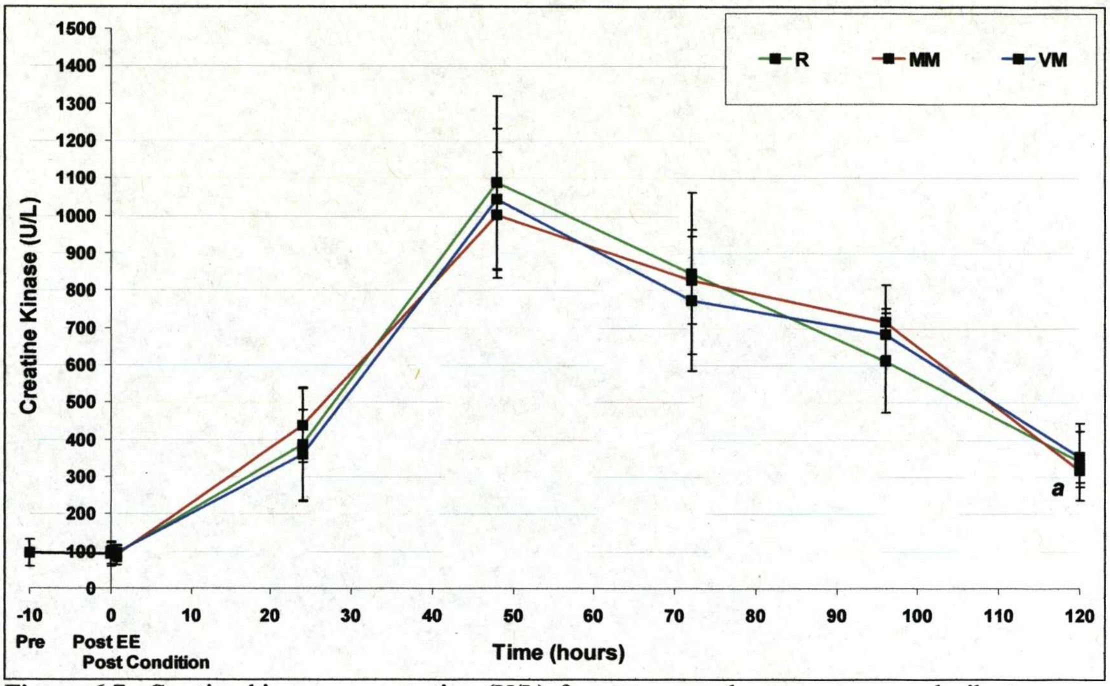


Figure 6.7 Creatine kinase concentration (U/L) for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences ***a*** = 120hrs *vs* baseline.

Figure 6.8 demonstrates that for R, MM and VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

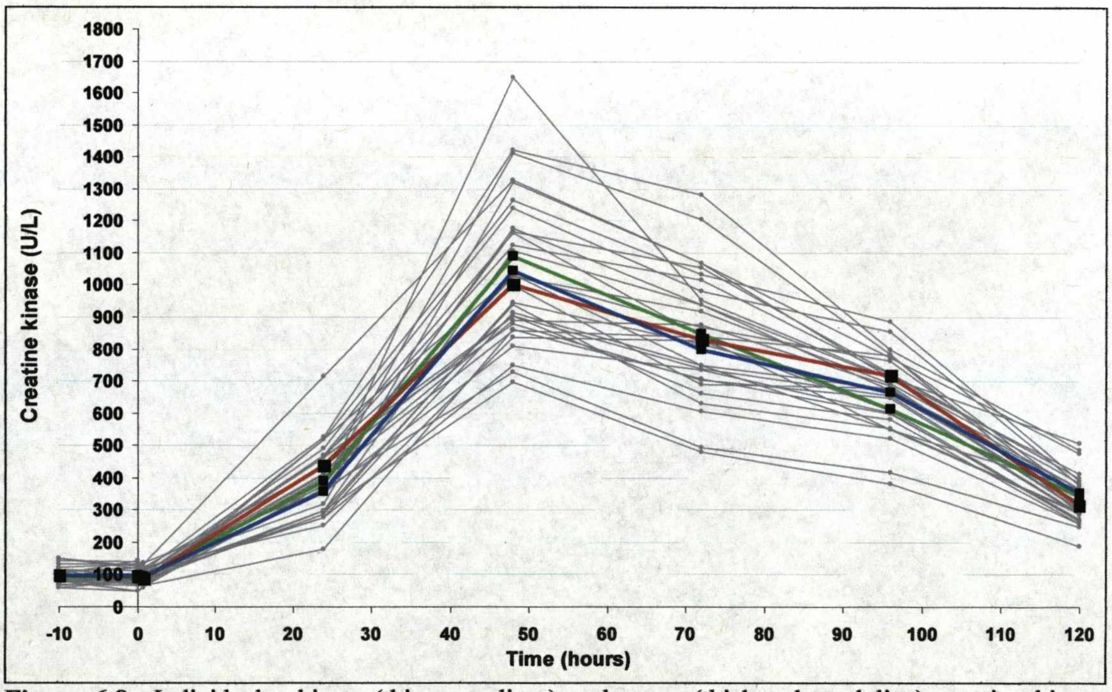


Figure 6.8 Individual subjects (thin grey lines) and mean (thick coloured line) creatine kinase concentration (U/L) for rest (R), for manual massage (MM) and vibratory massage (VM) prior to and for 120hrs following a bout of eccentric exercise (n = 30).

6.15 The effect of massage on limb circumference

Limb circumference (LC) increased by 22.6±5.4mm following the bout of EE (Figure 6.9), and increased a further 3.3±2.9mm (R), 2.4±1.6mm (MM) and 3.4±1.2mm (VM) following the 8min recovery period.

The highest LC were seen at 48hrs which were similar for all three conditions, peaking at 28±5.1mm (R), 26.1±3.9mm (MM) and 27.1±3.2mm (VM) above the baseline measurement ($p<0.0001$). At 120hrs, LC remained above the baseline measurement level (12.6±2.4mm (MM), 11.2±2.5mm (VM) and 11.2±1.8mm (R)). These values were all significantly higher than baseline (R ($p=0.018$), MM ($p=0.024$) and VM ($p=0.031$)).

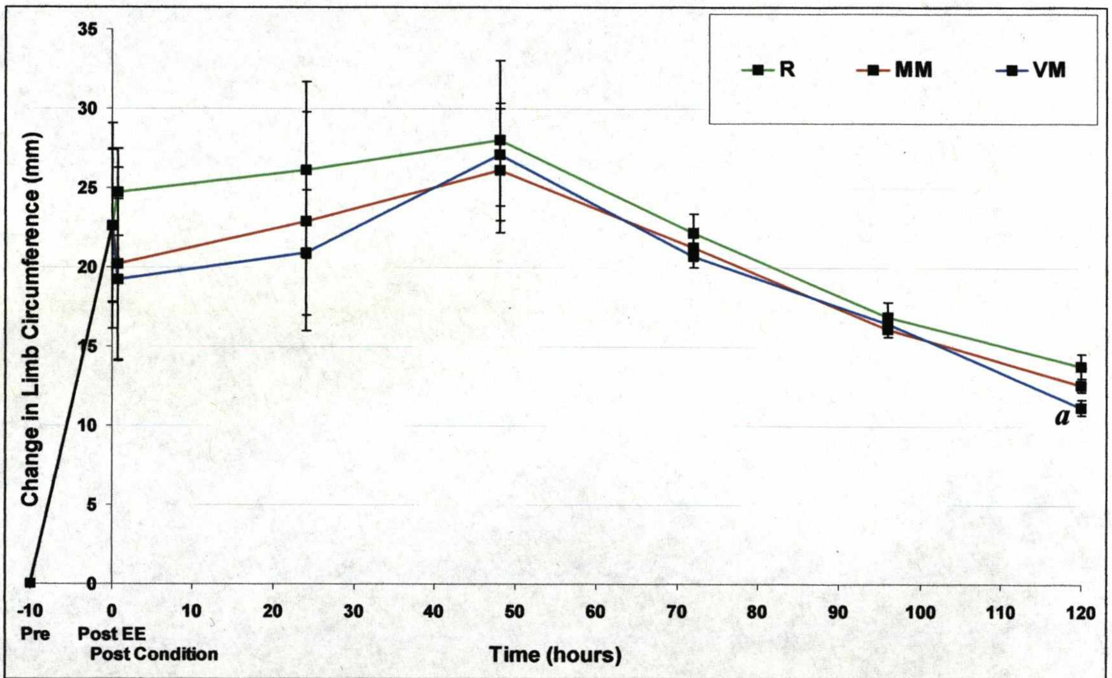


Figure 6.9 Limb circumference measurement for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences ***a*** = 120hrs *vs* baseline.

In conclusion, arm circumference increased significantly following the eccentric exercise bout. There was no significant difference between the recovery conditions indicating that neither MM nor VM reduced LC.

6.16 The effect of massage on muscle strength

On completion of the 8min recovery period, %1RM decreased to 71.3±9.4% (R), 72.6±8.5% (MM) and 74.1±11.2% (VM) which was significantly lower than baseline measurement; but there was no significant difference between the three treatment methods (Figure 6.10). MS began to return, but remained significantly lower than the baseline 1RM throughout the 120hr measured recovery period (p=0.026). By 120h, MS had returned to 92.4±2.3%, 94.2±4.7% and 93.2±2.8%1RM for R, MM and VM respectively. In conclusion, there was no significant difference seen between the three recovery modes at any time point.

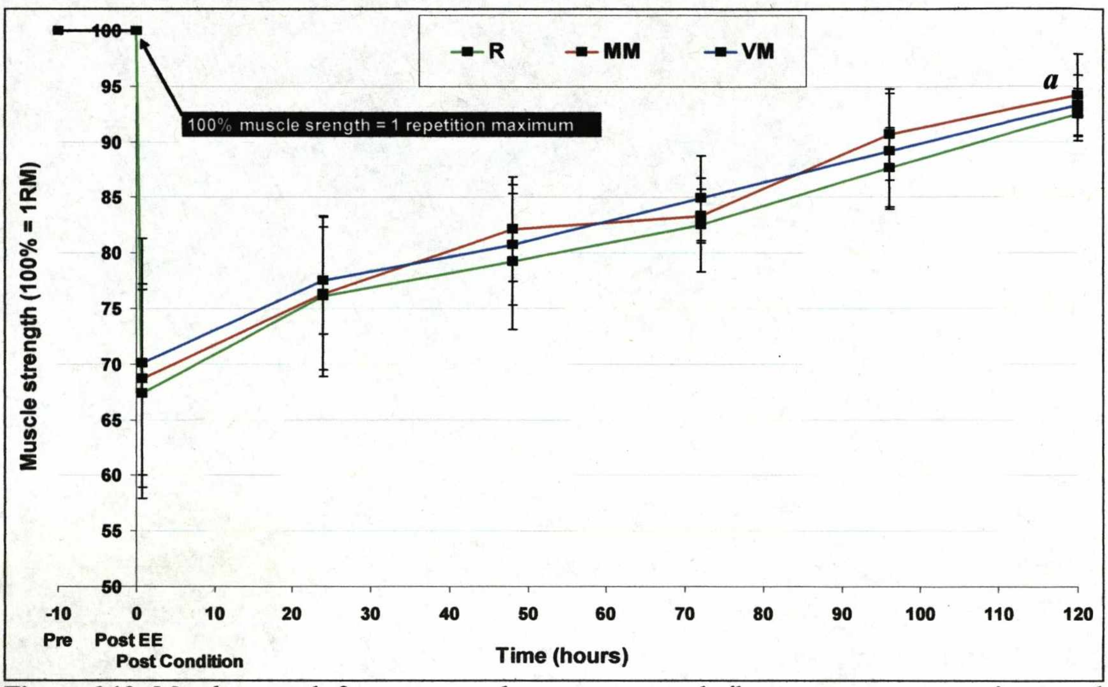


Figure 6.10 Muscle strength for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). 100% muscle strength = 1 repetition maximum. Significant differences ***a*** = 120hrs *vs* baseline.

6.17 The effect of massage on perception of pain

At baseline, subjects reported no pain in their exercise arm. This increased to its highest level (5 (IQR 4, 6) (Very painful)) on completion of the eccentric exercise bout (Figure 6.11). Perceived pain, following VM, was significantly lower (p<0.01) than MM from 4hrs to 96hrs recovery. The sensation of pain had subsided to 0 (No Pain) at 72hrs - 120hrs.

Following a decrease in pain sensation post MM to 3 (IQR 3, 5.25) (More than slight pain), it increased to, and was highest at 4 (IQR 3, 6) (Painful) at 8hrs. It then began to decrease, and by 120hrs subjects registered a perceived pain of 0 (IQR 0, 0.75) indicating that some subjects had a degree of residual pain.

For R there was a decrease in pain sensation following the 8min recovery, this then increased to, and remained constant at 4 (IQR 3, 5) up to 24hrs. It then began to decrease, and by 120hrs subjects registered a perceived pain of 0 (IQR 0, 1) indicating some subjects had a degree of residual pain.

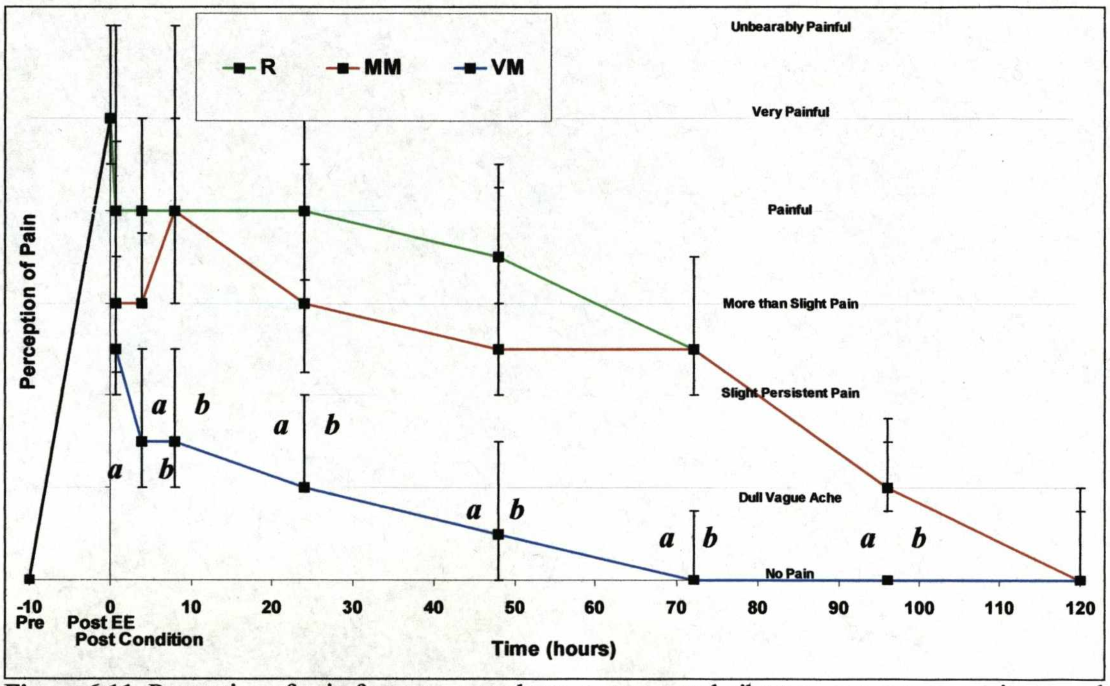


Figure 6.11 Perception of pain for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences (p<0.01) ***a*** = VM *vs* R and ***b*** = VM *vs* MM.

Figure 6.12 demonstrates that for VM the individual subjects all responded in a similar fashion to that depicted in the group mean.

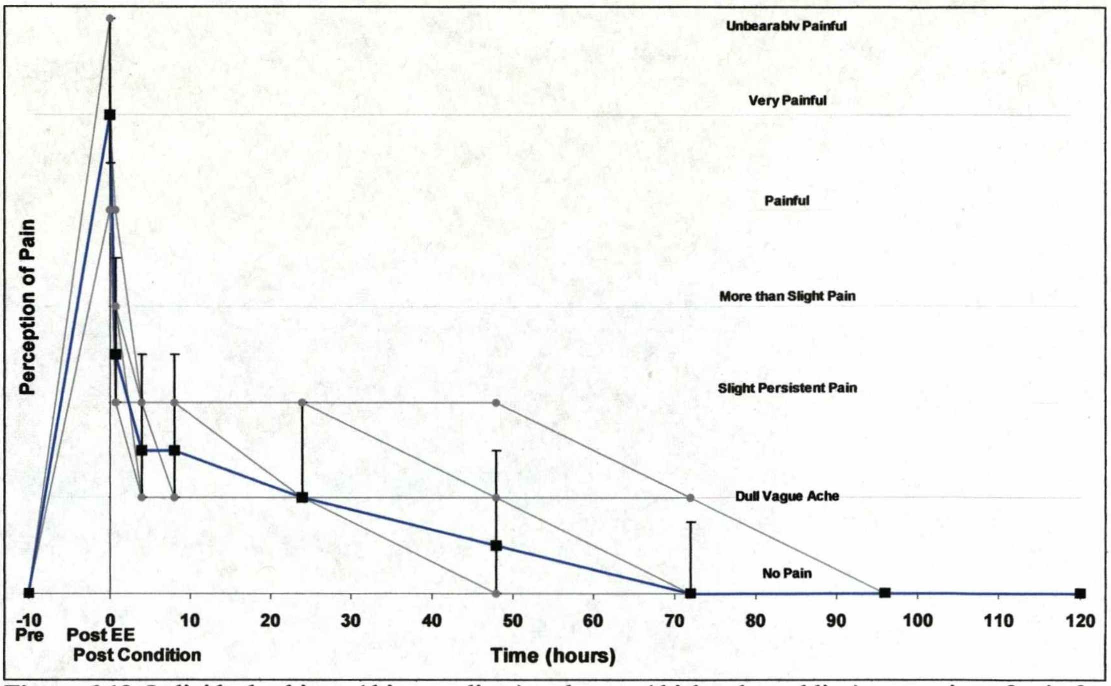


Figure 6.12 Individual subjects (thin grey lines) and mean (thick coloured line) perception of pain for vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise ($n = 10$).

In conclusion, 8mins of vibratory arm massage was successful at ameliorating the pain sensation following a bout of short tem intense eccentric exercise, compared to MM.

6.18 The effect of massage on perception of feeling

PoF decreased from 6 (IQR 5.5, 6.0) (Very Good) to -2 (IQR -2, -1.25) (Fairly Bad) immediately following the eccentric exercise bout. Feeling recovered slowly during R to 0 (IQR 0, -0.75) (Neutral) following the 8min recovery treatment, and then began to improve over the subsequent 24hrs (Figure 6.13). By 24hrs post EE, PoF for R was 1.5 (IQR 0, 2). In contrast, arm massage significantly improved perception of feeling immediately after the EE bout and for the 24hrs post (p<0.01).

Immediately following the 8min treatment, PoF had returned to 4 (IQR 2.5, 5.5) (Good) for MM and 4 (IQR 2.5, 4.75) for VM. At 24hrs post-EE PoF for MM was 4.5 (IQR 4, 5.75), and 6 (IQR 4.25, 6) for VM which was the same baseline measurement. No further measurements were taken after 24hrs as it was thought the extraneous factors rather than those directly related to the recovery from EE would affect perception of feeling.

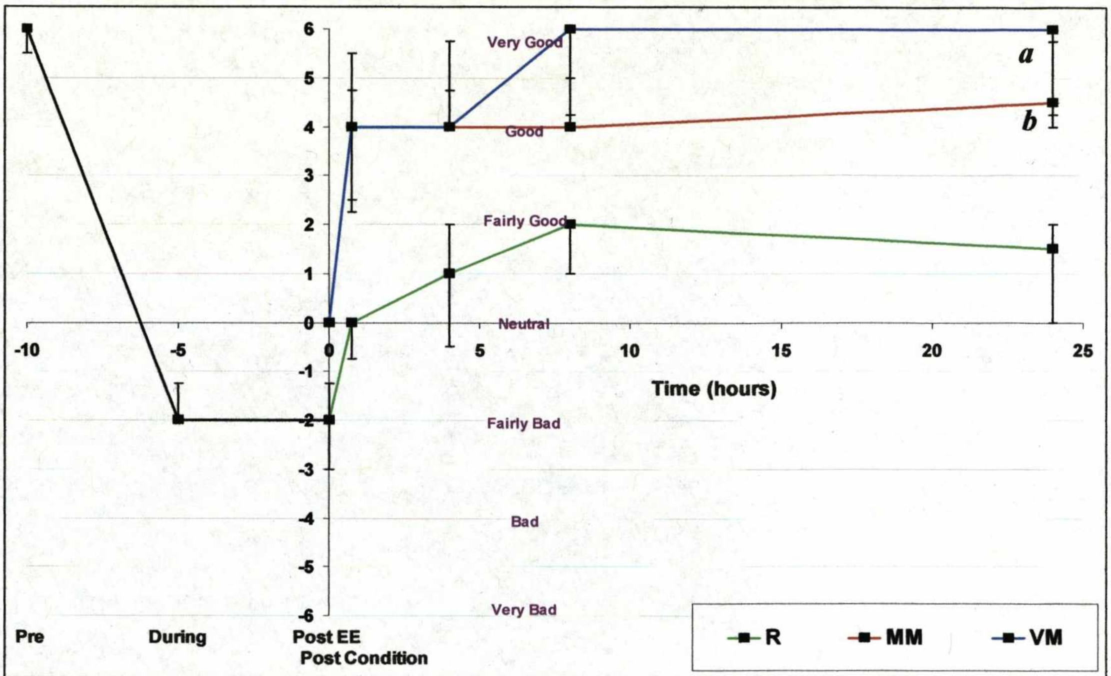


Figure 6.13 Perception of feeling for rest, manual arm massage and vibratory arm massage prior to and for 120hrs following a bout of eccentric exercise (n = 30). Significant differences (p<0.01) $\boldsymbol{a}$ = MM *vs* R and $\boldsymbol{b}$ = VM *vs* R.

6.19 Interaction between perception of feeling and perception of pain following a bout of eccentric exercise

There was a significant correlation between perception of pain (a measurement of muscle pain) and perception of feeling (a marker of mood) for up to 24hrs post EE. The lowest perception of feeling of -2 (Fairly Bad) corresponded with highest pain of 4.5 (IQR 4, 5.5) (Very painful) for all recovery conditions (Figure 6.14). Correlation analysis of these two variables for VM (r^2=0.7946) showed that there was a significant correlation, but not for MM (r^2=0.5588) or R (r^2=0.4919). The results indicate that as perceived pain decreased, mood state improved.

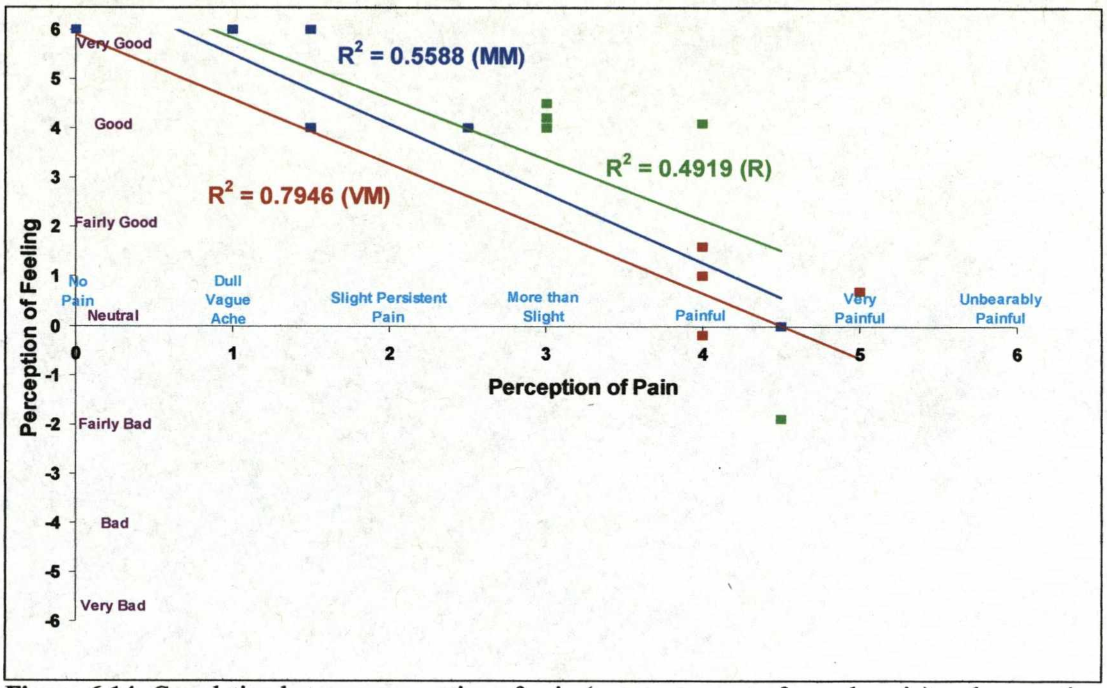


Figure 6.14 Correlation between perception of pain (a measurement of muscle pain) and perception of feeling (a marker of mood) for up to 24hrs post eccentric exercise bout.

DISCUSSION

6.20 The eccentric exercise bout

It appears from the rating of perceived exertion results that the subjects were near exhaustion from the exercise bout, and therefore the EE was deemed successful at causing muscular fatigue. In addition, it was expected that the exercise bout would subsequently cause an increase in CK (indicating muscle damage), perception of pain, limb circumference, and cause a decrease in strength. This has been the case with all other studies which have used a similar method and duration of eccentric exercise (Clarkson, Nosaka & Braun, 1992; Nosaka & Clarkson, 1996; and Lee & Clarkson, 2003).

6.21 The effect of massage on heart rate, blood pressure and rate pressure product following a bout of eccentric exercise

There was no significant difference between with the three recovery conditions either following the eccentric exercise bout, or post recovery for all cardiovascular variables measured. This indicates that massage does not have any greater effect on the parasympathetic system, compared to Rest, during recovery from eccentric exercise.

6.22 The effect of massage on creatine kinase and blood lactate clearance following a bout of eccentric exercise

The current investigation used the Reflotron® and quantified enzyme activity in whole capillary blood. This assay type has been shown to be a valid method of CK quantification when compared to other established methods (Braun, 1987), and has been previously used in similar studies. The highest group value recorded at 48hrs during this present investigation was 1045±226U/L, with a range of 697.9 - 1647.7 U/L. This accords with Fridén & Lieber (3846±276IU/L) and Howatson & Van Someren (2003) (799±699.1U/L) who both measured following at bout of EE. The inter-subject variability in CK occurred irrespective of recovery mode, as both the highest and lowest CK values occurred within the Rest group. This trend has been reported previously (Hortobágyi & Denham (1989), Nosaka & Clarkson (1996b) and Chen (2006)). Despite the large inter-subject variability in CK production, the general trend and clearance of CK is similar between the three recovery methods, and therefore this does not alter the final conclusion, that massage (manual or vibratory) failed to clear CK more rapidly than R.

It is generally accepted that CK is a reasonable predictor of muscle damage and subsequent muscle pain (Smith *et al.*, 1996). Rodenburg *et al.*, (1993) reports that there is a significant correlation between muscle soreness and CK activity (r^2=0.91). However, during this present investigation the two variables were not related, as shown by the poor correlation of r^2=0.012 (R), r^2=0.04 (MM) and r^2=0.27 (VM), because the highest pain scores did not accord with the highest CK values, which is the typical response.

There was no significant difference between with the three recovery conditions either following the eccentric exercise bout, or during the subsequent 120hrs; and CK remained significantly elevated above baseline at 120hrs. The findings are in agreement with other research using EE bouts followed by massage administration. Rodenburg, Steenbeek, Schiereck & Bärr (1994) reported that manual massage did not significantly reduce CK when massage was administered immediately after 30mins of eccentric forearm flexions, although they did see a reduction in perceived pain. Weber, Servedio & Woodall (1994) also concluded that a massage performed 0hrs and 24hrs after eccentric exercise had no significant effect at reducing CK. A more recent study by Farr, Nottle, Nosaka & Sacco (2002) had subjects walking down hill for 40mins, followed by a 30min massage; no significant difference was reported between massage and rest legs.

Conversely, several other studies have shown that CK is decreased more rapidly following a single or multiple periods of massage. Smith *et al.*, (1994) report that a 30min manual massage administered 2hrs following 175 eccentric exercise biceps contractions reduced serum CK levels from 8-120hrs when compared with the control resting group; also the sensation of pain was lower for the massage group. Furthermore Zainuddin, Newton, Sacco & Nosaka (2005) administered a 10min arm massage 3hrs following 60 maximal voluntary eccentric contractions, and established that plasma CK was lower when compared to the rest condition (Figure 6.15); in addition there was a significant 20-40% decrease in muscle soreness. All conclude, and hypothesised that less circulating CK following the massage condition may indicate *a*) an increased CK removal from systemic circulation, *b*) a smaller CK efflux from damaged muscle or *c*) a combination caused by an increase in blood and lymph flow to the muscle. There is no evidence to support the hypothesis of Zainuddin, Newton, Sacco & Nosaka (2005) in the present investigation, as there was no significant difference in CK concentration between the recovery conditions, and the mechanical action of massage did not decrease limb oedema (measure by limb circumference).

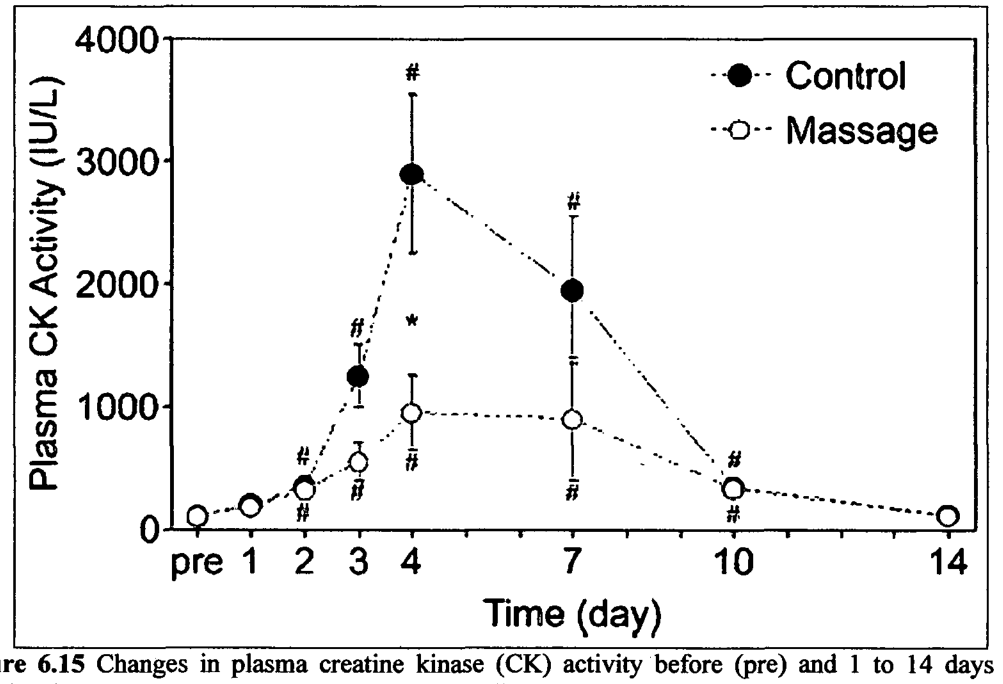


Figure 6.15 Changes in plasma creatine kinase (CK) activity before (pre) and 1 to 14 days post exercise for the massage and control arms. * Indicates a significant difference between arms; #, a significant difference from baseline. (Data from Zainuddin, Newton, Sacco & Nosaka, 2005).

In addition to the lack of effect of massage on CK, there was no significant difference in BLa concentration indicating that both massage conditions were ineffectual at promoting short term recovery from the eccentric exercise bout. A more detailed discussion regarding the effect of massage on lactate clearance is in Chapter 5.

6.23 The effect of massage on limb circumference following a bout of eccentric exercise

Swelling commonly peaks at 48-120hrs (Chelboun *et al.*, 1995; and Zainuddin, Newton & Nosaka, 2005). During this present investigation, LC was highest at

48hrs. As measurements were not taken beyond 120hrs, it is not possible to speculate when LC would have returned to baseline. The increase in girth of 20-25mm during this present investigation is consistent with other studies that used eccentric contractions to cause muscle damage (Nosaka & Clarkson, 1996a; Howell, Chleboun & Conatser, 1993; Nosaka, Newton & Sacco 2002; and Chen, 2006).

Albury, (1934a b) and Rinder & Sutherland (1995) state that manual massage has a positive effect at clearing oedema from affected limbs; however, little research evidence is available to substantiate the claim. Hart, Swanik & Tierney (2005) massaged 19 subjects at 24, 48 and 72hrs post EE of the hamstring and observed that oedema cleared from the affected area following massage, but this was only temporary, and oedema returned after the cessation of massage therapy. The same trend was seen during their control treatment of light concentric leg exercise. Conversely Zainuddin, Newton, Sacco & Nosaka (2005) concluded that manual massage went some way towards preventing the limb swelling after 60 maximal voluntary eccentric contractions of the elbow, and at 96hrs there was a significant difference of 7.1mm between the massaged and rested arms, and by 14days there remained a 4.1mm difference. They also reported a reduction in pain by 30%, and concluded that the two variables are in some way correlated; i.e. the less accumulation of lymph at the injury site, the lesser the pain. The correlations for MM and Rest indicate that limb girth and pain follow the same course, and therefore it would be plausible to conclude that Hart, Swanik & Tierney (2005) are correct in assuming that both pain and limb girth may disappear naturally with the passage of time, irrespective of recovery mode. Conversely, the response for VM was different, as there was no significant correlation between limb girth and pain for vibratory massage (r^2=0.17), despite pain decreasing rapidly and disappearing by 72hrs, limb girth remained elevated at 5 days, and possibly beyond. Once again, this suggests that the overriding response of VM is neutrally mediated.

<u>6.24 The effect of massage on strength recovery following a bout of eccentric exercise</u>

During this present investigation, the application of manual or vibratory massage immediately following the eccentric exercise bout had no beneficial effect on strength recovery. Furthermore, despite alleviating pain, vibratory massage had no greater effect than Rest. This decrease in muscle strength to 70% of 1RM and failure to return to normal within 120hrs is consistent with many other research studies (Tiidus & Shoemaker, 1995; Hilbert, Sforzo & Swensen, 2003; Jönhagen, Ackermann, Eriksson, Saartok & Renstrom, 2004; and Zainuddin, Newton, Sacco & Nosaka, 2005). Furthermore, it is apparent from the literature that irrespective of the duration or type, massage has no effect on strength recovery.

6.25 The effect of massage on perception of pain and perception of feeling following a bout of eccentric exercise

6.25.1 Perception of pain: It is evident from the empirical research available that the type and duration of manual massage differs greatly; however, it shares a common goal, which is to reduce pain (Hilbert, Sforzo, Swensen, 2001 & 2003; and Hart, Swanik & Tierney, 2005). In this present investigation, the highest pain for all conditions (5 (IQR 4, 6); 'Very Painful') was recorded immediately following the EE bout, and subsided at different rates for the three conditions. This is contrary to the majority of studies, and the established model, that pain peaks between 24-48hrs post EE and then reduces over subsequent days (Kuipers, 1994; Weber, Servedio & Woodall, 1994; Warren, Lowe & Armstrong, 1999; and Hemmings, 2001). The subjects were introduced to, and familiarised with the seven point pain scale prior to the start of the study; therefore, no plausible explanation can be offered as to why the highest pain score did not occur later. However, it is not considered that this affects the final conclusion of the investigation, as subjects did suffer considerable pain following the eccentric exercise bout.

As manual massage is routinely used to aid recovery, it has been postulated that massage administered during the very early stages of muscle injury could increase circulation and lymphatic flow, in addition to decreasing muscle tension, which would in some way to decrease pain and reduce localised inflammation (Cafarelli, Sim, Carolan & Liebesman, 1990; Goats, 1994 and Weber, Servedio & Woodall, 1994) and, Tiidus, 1999). With vibratory massage, most data reported in the literature concentrates on its use to alleviate chronic back pain at a frequency of 50-150Hz (Lundburg *et el.*, 1984), to alleviate pain following maximal voluntary muscle contractions at 80Hz (Cafarelli, Sim, Carolan & Liebesman, 1990), and numb areas in preparation for cosmetic procedures at 95Hz (Smith, Comite, Balasubramanian, Carver & Liu; 2004). Within these studies, it is reputed that vibratory massage should be applied near or distal to the site of pain (Ottoson, Ekblom & Hasson, 1981; Sherer, Clelland, O'Sullivan, Doleys & Canan, 1986; Lundeburg, 1986; and Cardinale & Wakeling, 2005), and that it reduces the perceived pain experienced by acute and chronic pain sufferers possibly by closing pain gates within the dorsal horn (Melzack &Wall, 1965 & Smith *et al.*, 2004).

The pain gate theory proposed by Melzack & Wall (1965) and Melzack (1999) suggests that the nociceptor activity from the small diameter nerve fibres (Figure 6.16a) can suppress second order neurons by a gating mechanism within the dorsal horn through the high level stimulation of large diameter myelinated A-beta nerve fibres (Figure 6.16b) (Melzack, 1999). There are significant numbers of A-beta fibres in the skin, therefore vibration stimulation may cause the inhibition of nociceptor transmission, and thus ameliorate or withdraw the pain sensation association with post eccentric exercise (Carlsöö, 1982; Latham, 1985; Sherer, Clelland, O'Sullivan, Doleys & Canan 1986; Horn & Munafò 1997; and Sofaer, 1998).

A

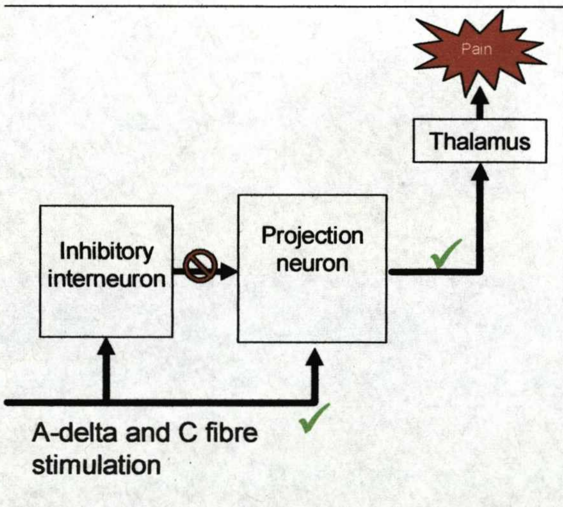


Figure 6.16a Pain action potentials transmitted via the A-delta and C fibres synapse with the first interneuron (adapted form Kandell, Shwartz & Jessell, 2000)

B

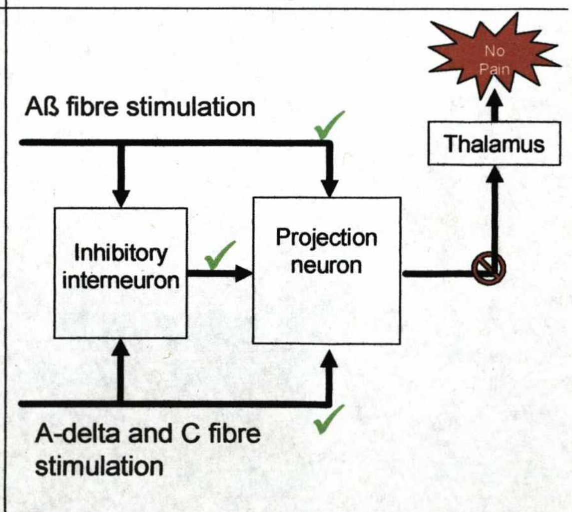


Figure 6.16b Firing of the A-beta fibers actives the inhibitory interneuron, reducing the possibility that the projection neuron will fire, even in the presence of a firing A-delta and C fibers (adapted from Kandell, Shwartz & Jessell, 2000).

The 60Hz vibration from the G5 would be expected to stimulate and oscillate mechanoreceptors in the skin which would develop action potentials that transmit through the neural A-beta afferents. The mechanoreceptors responsible for vibration sense include Merkel discs and Meissner's corpuscle receptors within the superficial layers of the skin, and the Pacinian corpuscles between the muscle layers and periosteum (Marieb, 2006). Meissner's corpuscle receptors respond maximally to stimuli of 20-60Hz (Gilman, 2002), and Pacinian corpuscles to a frequency of 60-400Hz (Bolanowski & Zwislocki, 1984a b); therefore these will be the two fibre types (A-*beta*) which are most likely to respond to the vibration emitted by the G5, and thus prevent A-delta and C fibres from transmitting second order neurons within the dorsal horn by the pain gate mechanism. As Merkel discs respond maximally to vibrations between 5-15Hz (Gilman, 2002), these may not contribute a significantly in pain amelioration, as the frequency of the vibratory massage in the present investigation was set at a higher frequency of 60 Hz.

The pain perception for R and MM were similar, and therefore MM did not prevent or ameliorate pain whereas VM significantly reduced pain probably by the pain gate mechanism. However, in the case of MM, the administration of massage was at a frequency of 0.2Hz, and therefore would not stimulate the three A-beta mechanoreceptors maximally. This may therefore be the reason why MM did not have a significant impact at ameliorating pain caused by the eccentric exercise bout.

The second possible mechanism that may contribute to a decrease in pain and/or an increase in relaxation following massage maybe due to a decrease in muscle tension; and the perception which follows this. Tone is maintained through muscle spindles within the skeletal muscle, and therefore any decrease in alpha motorneuron excitability mediated through massage repeated lengthening, stretching and twisting may cause a decrease in muscle tension (Sullivan, Williams, Seaborne & Morelli, 1991). The studies which have quantified the effect of massage on alpha motorneuron excitability have used H-reflex in order to measure change (Weerapong, Hume, Kolt, 2005).

Sullivan, Williams, Seaborne & Morelli (1991) reported that H-reflex was recorded from the distal aspects of the right triceps surae. Following 5mins of petrissage, H-reflex for massage (0.82mV) was significantly lower that of control rest (1.95mV). This response was also reported by Morelli, Chapman & Sullivan (1991) where massage was applied to the same muscle for 3mins. This response was again unequivocal, H-reflex for massage was significantly lower than control rest. Furthermore, Goldberg, Sullivan & Seaborne (1992), Morelli, Chapman & Sullivan (1999) and Dishman & Bulbulian (2001) have also report the effect and conclude that the effect does not originate from the stimulation of the cutaneous mechanoreceptors, and therefore the inhibitory effect must originate within the skeletal muscle proprioceptors, and thus leading to a decrease in tone, and thus relaxation. The response of VM on alpha motorneuron excitability has yet to be fully elucidated; however, Kawanishi, Yahagi & Ribot (1999) concluded that the administration of vibratory massage at 30Hz to the biceps femoris muscle depressed H-reflex, and therefore exhibited the same response as manual massage.

The final receptor which may respond to manual or vibratory massage is the golgi tendon organ (GTO) (Marieb, 2006), by causing inhibition though pressure being applied to the tendon, causing overload which in turn causes reflex inhibition (Cassar, 2004). In this respect, Roll, Vedel & Ribit (1989) observed that vibration to the tendons of the tibialis anterior and extensor digitorum longus muscles at 80Hz had little or no effect on alpha motorneuron excitability in relaxed muscle.

The above evidence suggests that alpha motor neurone excitability may be reduced though activation of muscle proprioceptors such as muscle spindles but not through cutaneous receptors or golgi tendon organs. Thus, the relaxed muscle and spindles provide the sensory perception of relaxation in the muscles following both vibratory and manual massage.

The final possible mechanism by which massage may ameliorate pain following acute muscle damage is through inhibition of neurotransmitters. Substance P (SP) is one such neurotransmitter which has an intrinsic role in nociceptive transmission (Wood, 2002), and is released following damage to tissue cells (McHugh & Much, 2000; and McKawan *et al.*, 2001), and located in the sensory neurons in laminae 1 and 2 of the dorsal horn (Nichols *et al.*, 1999). Research has shown that following the application of manual massage (or firm skin stroking (Morhenn, 2000), there is a decrease in salivary SP and therefore nerve conductivity to the cerebral cortex is modified or limited thus decreasing perception of pain (Wood, 2002). Field *et al.*, (2002) administered a 30min upper body massage twice weekly for 5 weeks to 20 patients with fibromyalgia. The massage decreased SP concentration, decreasing from 84.1 to 69.2 $pg \cdot ml^{-1}$, compared to an increase from 71.9 to 111.1$pg \cdot ml^{-1}$ for the control relaxation group. In addition, Mackawan *et al.*, (2007) reported that a single 10min bout of massage decreased salivary SP concentration from 73.86 to 50.43$pg \cdot ml^{-1}$ in 35 subjects. As well as the observed decrease in SP following single (Mackawan *et al.*, 2000) and multiple (Field *et al.*, 2002) bout(s) of massage; both studies also reported that the decrease (in SP) correlated highly with an amelioration in perceived pain and an increase in mood state.

Although both aforementioned studies have shown a decrease in SP response following manual massage, there is paucity regarding the effect of vibratory massage. There are three studies available which have investigated the effect of vibration on substance P; one on humans and the other two have used rabbits to observe a response. Weinstein (1986) and Weinstein, Pope, Schmidt & Seroussi (1988) both observed that following moderate whole body vibration of rabbits there was a significant decrease in SP concentration. Furthermore, Guieu, Tardy-Gervet & Giraud (1993) studied the effect of a 30min whole body vibratory massage administered to seven chronic pain suffers. The authors observed a significant decrease in SP concentration following the VM bout, however they concluded that the response may have been too slight to have a definite effect on pain; they did not correlate the SP decrease with an analogue pain scale.

The lack of effect by manual massage in this investigation accords with the conclusions of Weber, Servedio & Woodall (1994); Jonhagen *et al.,* (2004); and Hart, Swanik & Tierney (2005), where massage did not positively affect pain. Unlike this present investigation, these three studies used multiple bouts of massage administered over a period of days, thus indicating that a single massage or multiple bouts of massage are ineffective at reducing both acute and chronic pain. These studies all conclude that the use of massage should be questioned as a post exercise method of recovery because there is no apparent physical gain.

Conversely other studies, using single or multiple bouts, have reported that manual massage has been effective at reducing pain following eccentric exercise. Smith *et al.*, (1994) report that a 30min manual massage administered 2hrs following 175 bicep eccentric contractions at 75%1RM, reduced the sensation of DOMS for 5 days when compared with the control resting group. Zainuddin, Newton Sacco & Nosaka (2005) also report that massage is effective at reducing pain by 20-40% following a 10min arm massage, which was preceded by 60 maximal isokinetic eccentric arm actions. Farr, Nottle, Nosaka & Sacco (2002) also report that a 30min manual massage administered 2hrs post was effective compared to rest at attenuating perceived pain following a 40min downhill run. Their conclusions suggest that when short term pain management is a priority then massage is a useful recovery mode and should be used.

Tiidus & Shoemaker (1995) hypothesised that if superficial and deep effleurage techniques improve lymph flow, removing oedema from the site of muscle damage, then pain sensation would be less in subjects following eccentric quadriceps contractions. The results of the research by Tiidus & Shoemaker (1995), and those of this present investigation do not support this hypothesis. However, the results by Tiidus & Shoemaker (1995) indicated that the sensation of pain was lower at 48hrs - 96hrs in the massage group compared to rest, although muscle strength was not significantly different from the control group during the same time period. This is contrary to this present investigation were perception of pain remained above baseline for 96hrs, and strength had not returned to baseline at 120hrs.

The research by Smith *et al.*, (1994); Farr, Nottle, Nosaka & Sacco (2002), and Zainuddin, Newton Sacco & Nosaka (2005) all conclude that manual massage has positive effects on pain following EE. However, the conclusion of this present investigation is that a single bout of manual massage is not an effective treatment for enhancing short term recovery from a bout of exhaustive eccentric exercise. This may have been because the duration of the massage administered by Smith *et al.*, (1994) and Farr, Nottle, Nosaka & Sacco (2002) was considerably longer than the 8mins in this present investigation. However, Zainuddin, Newton Sacco & Nosaka (2005) massaged the whole arm for only 10mins using a similar massage sequence, and noted a significant effect. Therefore, the duration of massage may have no bearing on a subject's outcome following a bout of eccentric exercise.

6.25.2 Perception of feeling: In conjunction with the seven point pain scale, perception of feeling was measured on a 13 point good/bad scale to assess mood state. To ensure that the subjects' prior perceptions did not affect the overall result, only those who had not previously received any form of massage were tested during this present investigation. This was an important factor, as Jönhagen, Ackermann, Eriksson, Saartok & Renström (2004) state that subjects who have previously received massage may react differently to those have not, and their personal expectations may affect the result or influence the outcome, independent of the treatment (Kalauokalani, Cherkin, Sherman, Koepsell & Deyo, 2001). Furthermore, Tan, Roux, Dunand & Vischer (1992) suggest that the vast majority of subjects may be "delighted" to receive a massage after exercise, irrespective of their beliefs regarding the efficacy of massage.

The present study's findings accord with those of Tiidus & Shoemaker (1995), who suggest that the use of manual massage in an athletic setting should be questioned, as massage (manual and vibratory) may have a greater psychological than physiological effect; in this respect following acute muscle damage. This investigations results show that both MM and VM increased PoF following the EE, and were near normal at 24hrs; this is despite significant increases in pain, creatine kinase, limb girth, and lower muscle strength.

In conclusion, in respect of perception of pain, previous research has reported that vibratory massage is more effective when administered to sufferers of chronic pain. However, the present investigation has demonstrated that VM at 60Hz is also effective at ameliorating the acute pain associated with exercise induced muscle injury, and it seems reasonable to speculate that one or a combination of the three aforementioned pain reduction mechanisms (pain gate theory, muscle tone decrease and neurotransmitter activity reduction) may contribute to this decrease.

CONCLUSIONS

6.26 Conclusions

6.26.1 The results of this present investigation indicate that vibratory massage is more effective than manual massage or Rest at reducing muscle pain induced by eccentric exercise. This effect does not appear to be mediated through less muscle damage (as judged by creatine kinase release), by decreased oedema (as judged by limb circumference) or by indicate muscle strength recovery. The response may be due to a greater mechanical stimulation of the skin and muscle by vibratory massage, which may subsequently close pain gates.

6.26.2 Despite this positive conclusion the implications and practical application should be considered with caution. Pain is normally an indication of injury, and is self limiting. However, if subjects have no pain, but have compromised muscle strength, decreased range of motion and increased limb circumference, then this puts joint under pressure and unable to stabilise as normal (Cleak & Eston, 1992). To this end, there should be reservations regarding the use of massage as an intervention for strength restoration and recovery post exercise

CHAPTER 7

DISCUSSION AND STUDY CONCLUSIONS

7.1 Overview

The intention of this chapter is to present the main findings, and answer the research questions presented in the Chapter 1. This chapter will critically evaluate the effect of massage on each of the physiological and psychological variables investigated in the study. Furthermore, it will speculate on and propose possible mechanisms to account for the physiological and psychological effects of massage when it is administered at rest, or during recovery from exercise.

7.2 The effect of manual and vibratory on cardiac autonomic activity, heart rate, blood pressure and rate pressure product.

7.2.1 Heart rate variability and heart rate: The data presented in his study form the first investigation into the effects of leg massage on cardiac autonomic activity. The results suggest that following manual and vibratory massage, there is an evident and consistent decrease in sympathetic activity and increase in parasympathetic activity, when compared to passive Rest.

It is evident from the results presented here that both MM and VM caused a decrease in heart rate, blood pressure and rate pressure product. The results of this study therefore have implications for the use of whole leg, or calf massage as a therapeutic means for inducing a relaxation response either at rest, or during recovery from exercise. These responses are consistent with the findings of Delaney, Leong, Watkins & Brodie (2002) and McNamara, Burnham, Smith & Carroll (2003) who also noted an increase in parasympathetic drive and decrease in sympathovagal balance following a manual neck, shoulder and back massage; although both aforementioned studies did not propose the mechanism or mechanisms responsible.

However, in terms of an overall mechanism or mechanisms responsible for massage induced changes in physiological and psychological parameters observed in this and other studies, it appears feasible to suggest that they may be, at least in part, due decreased sympathetic activity. In this respect, although purely speculative (and direct measurement being beyond the scope of this study), the potential link between massage and catecholamine release is of interest; and evidence from the perception of feeling and blood presssure potentially support this reduction. The perception of feeling results may be indicative of a reduction in stress and enhanced relaxation, and thus a decrease in circulating catecholamines. Furthermore, this reduction in adrenaline and noradrenaline would reduce the sympathetic influence upon the sinoatrial node and arterioles, which in turn would cause an increase in heart rate variability, and a decrease in heart rate and blood pressure respectively. Previous studies have reported this potential decrease in circulating catecholamines. Kurosawa, Suzuki, Utsugi & Araki (1982) on rats clearly demonstrated that massage-like stimulation of the abdomen (and other regions), resulted in a decreased activity of the adrenal glands and lowered levels of adrenaline and noradrenaline. Decreased activity in the efferent sympathetic nerves was also demonstrated. In addition, Acolet *et al.*, (1993) also reported a decrease in circulating catecholamines in premature babies who received regular massage.

The subjects in this study were normotensive males with no health concerns. Therefore, it may not be prudent to generalise the effects from healthy subjects to diseased populations. However, McNamara, Burnham, Smith & Carroll (2003) administered a massage to hypertensive males and females (64.9yrs) and reported an increase in HRV high frequency activity (parasympathetic). Therefore, it is possible that leg massage would cause a similar response for older hypertensive patients. Moreover, a relaxation response would indeed be beneficial for such diseased populations, such as those with uncomplicated hypertension, diabetics, and individuals who have suffered a recent myocardial infarction. All may benefit from leg massage in order to decrease cardiac stress, as these aforementioned medical conditions have been shown to decrease HRV, thus indicating an increase in sympathetic activity and sympathovagal tone (TaskForce, 1996, and Lord *et al.*, 2001). Nevertheless, what must be considered with these patients would be other medical complications, such as deep vein thrombosis or thrombophlebitis, which would contraindicate receiving a leg massage (Ernst, 2003; Batavia, 2004; and Myklebust & Iler, 2007). Massage administered to patients with these conditions could be counterproductive, as increased external pressure administered at the site of inflammation would encourage the formation of clots, and also cause the emboli to spread.

Furthermore, the subject population in the present investigations were adult males; consequently, it may not be prudent to infer the same response in females. However, Delaney, Leong, Watkins & Brodie (2002) have shown a very similar sympathovagal response for female and male subjects following a neck and shoulder massage (16 females, 30.94±1.72yrs, and 14 males, 34.4±2.74yrs) using the Polar software. Therefore, it is possible that leg massage would cause a similar response for female subjects.

7.2.2 Blood pressure: It is evident from the investigations that manual and vibratory massage caused a slight decrease in systolic blood pressure, which is in accordance with the findings of Barr & Taslitz (1970), Longworth, (1982), Delaney, Leong, Watkins & Brodie (2002); and Aourell, Skoog & Carlson, (2005), who also reported this response. Again it may be speculated that there responses can be explained by a decrease in sympathetic activity to the arterioles which would cause vasodilatation, thus causing a decrease in blood pressure and cardiac output.

It was evident that the massage conditions did not have any significant effect on diastolic blood pressure following eccentric and aerobic exercise. However, following anaerobic exercise, despite failing to return DBP to baseline at 45mins following the WAnT, it was evident that the DBP for the massage conditions was higher by 5mmHg than the value for Rest. This response, although not statistically significant, may have some physiologically significant and thus have a beneficial effect on post exercise recovery which in turn may account for the statistically significant difference seen in the perception of feeling.

7.2.3 Rate pressure product: Despite massage not having a significant effect on systolic blood pressure, when combined with heart rate the results indicate a significant influence on rate pressure product. Without exception, the RPP variable decreased with both massage conditions, indicating a decrease in cardiac workload, and possibly an alteration in sympathovagal balance. As such, massage may have potential as an inexpensive surrogate indicator of sympathovagal balance. However, it is clear that further research using both males and females of a wide age range is required in order to robustly test this hypothesis.

7.3 The effect of manual and vibratory massage on respiration.

In addition to an alteration in cardiac autonomic activity, it was apparent that vibratory and manual massage both had a similar effect on respiration. These responses accord with the findings of Hayes & Cox (1999) and Doering *et al.*, (1999) who both reported a similar decrease in respiratory rate following massage; but proposed no mechanism to explain the response. As stated previously, massage will have no direct effect on the motor drivers of respiration; however, as there is an evident increase in parasympathetic drive, and this may have an effect by causing smooth muscle bronchoconstriction, thus increasing tidal volume and a concomitant decrease in respiratory rate.

7.4 The effect of manual and vibratory massage on leg skin and aural temperature.

7.4.1 Leg skin temperature: Limb skin temperature was shown to increase when both MM and VM were administered; however, without exception the leg skin temperature was higher for VM. MM and VM caused an average increase in leg skin temperature of 7.9% and 9.6% respectively, which compared to an average change of only 0.49% during Rest. This response would be most obviously explained as resulting from the friction between the therapists hands and subjects skin causing vasodilatation capillaries of the skin. In terms of the present study, it is also of interest that Gupta, Goswami, Sadhukhan & Mathur (1996) suggested that an increase in skin temperature causes an increase in muscle temperature, which in turn may lead to a temperature dependent increase in metabolic rate and limb blood flow.

7.4.2 Aural temperature: In addition to this localised effect of massage on the skin, there was a concurrent increase of 1.0% and 1.6% in aural temperature when both VM and MM was applied respectively. This compared to an average increase of only 0.07% during Rest. Furthermore, the increase in both aural and skin temperature show a high degree of correlation (r^2=0.897), thus indicating that massage has a comparable effect on core body temperature. It may be speculated that the change in aural temperature could be explained by increased venous blood temperature resulting from massage induced increase in skin and muscle temperature.

7.5 The effect of manual and vibratory massage on limb blood flow (measured using a plethysmograph).

This series of investigations is the first to examine the effect of vibratory massage on limb haemodynamics compared to MM. The limb blood flow data presented in this study demonstrate that manual and vibratory massage has no obvious effect on this physiological function, either at rest or following exercise. The lack of effect, coupled with the diversion of blood to the skin (deemed from an increase in skin temperature) may lead to a net decrease in muscle blood flow. Therefore, the conclusions of this study are in accordance with the findings of Shoemaker, Tiidus & Mader (1997), Drust *et al.*, (2003) and Hinds *et al.*, (2004) who reported no effect. Furthermore, as massage does not cause an increase in limb blood flow, it may be contraindicated as a warm up strategy for exercise, and could be counterproductive as a method of recovery from exercise, as the blood is diverted from the muscle to the skin.

7.6 The effect of manual and vibratory massage on blood lactate concentration following exercise.

In this study, the effect of massage on BLa concentration during short term post exercise recovery has been equivocal. Following a bout aerobic cycling exercise, there was no significant difference between MM, VM and R at the end of the recovery period. Similarly, BLa increased during the eccentric exercise bout, and once again, there was no significant difference between the three recovery methods at the end of the recovery period. This response is consistent with the majority of other studies who have investigated the effect of massage on BLa post exercise recovery, and reported no beneficial effect (Gupta, Goswami, Sadhukhan & Mather, 1996; Martin, Zoeller, Robertson & Lephart, 1998; Hemmings, Smith, Graydon & Dyson, 2000; Mondero & Donne, 2000; Robertson, Watt & Galloway, 2004; and Ogai, Yamane, Matsumoto & Kosaka, 2008). However, changes were evident following anaerobic exercise, and in response to MM and VM, during continuous and combined recovery, blood lactate concentration was consistently lower when compared to passive Rest. These results are in agreement with the findings of the preliminary study by Jones & Cotterell (1999) and the preliminary study in Appendix 2, which indicated the same response.

As stated in Chapter 5, the changes evident in blood lactate concentration following massage (MM and VM) would be expected to be a result of either a decreased anaerobic metabolism during massage, decreased efflux from the muscle or increased use of lactate by the muscle cells. Although this study has shown that BLa concentration post massage were consistently lower when compared to Rest alone, determination of which mechanism or mechanisms responsible were beyond the scope of the study.

However, one might assume that increased temperature may be a determinate in this respect, and as previously stated it is evident that increased skin temperature following manual massage leads to and increase in muscle temperature (Drust *et al*,. 2003). It was however clear in the present study that both MM and VM post exercise demonstrated a consistent increase in oxygen uptake and carbon dioxide output across the entire post WAnT period. Although this increase was not statistically significant when compared to Rest, it is possible that this increase again may be a temperature dependent response as a result of massage, and indicative of a decreased reliance on anaerobic metabolism and an increased aerobic metabolism by the muscles, which may directly account for the decrease in BLa concentration.

These aforementioned results may also have implications for the use of massage as a method of recovery from exercise. As manual or vibratory massage following aerobic and eccentric exercise did not decrease BLa concentration compared to passive Rest, then its efficacy as a mode of recovery from these types of exercise is questionable. However, following short term anaerobic exercise, massage is effective at decreasing BLa concentration, and enhancing PoF (compared to Rest) despite not preventing a decrease in DBP.

Furthermore, combining massage with CE is even more effective, which has implications for its successful appliance in an athletic setting. This combined method of recovery may be of use to athletes in sporting events which require short maximum exertions, where BLa concentration is increased, performed several times over the course of day e.g. track cycling championships, or swimming galas. For the first 15mins of recovery, exercise specific active recovery is recommended at an intensity equivalent to 60%HR_{max}, followed by a massage of the primary agonist and antagonist muscles used during the exercise, thus further eliminating BLa and increasing psychophysiological relaxation. This combined recovery method could prevent DBP undershoot, by maintaining blood flow and peripheral resistance, and potentially reduce when at its highest. In turn, muscle glycogen would be preserved, which would benefit the athlete for further events.

7.7 The effects of manual and vibratory massage on psychological wellbeing.

7.7.1 Perception of feeling: In addition to investigating the physiological effects of massage, the psychological effects were also considered, and in light of the overall findings of the study, perception of feeling may be of significance in ascertaining a potential mechanism involved in massage induced changes in physiological and biochemical parameters. Without exception, the results of the study demonstrate perceived relaxation and positive mood improvement, when comparing manual and vibratory massage to Rest. In part, this positive psychological response is consistent with research reported by Longworth (1982), Boone & Cooper (1995), Field *et al.*, (1996), Leivadi *et al.*, (1999), Zeitlin, Keller, Shiflett, Schleifer & Bartlett (2000), Hemmings (2000 and 2001), Aourell, Skoog & Carleson (2003), Delaney, Leong, Watkins & Brodie (2002) and Diego, Field, Sanders & Hernandez-Reif (2004) who found a similar response in perceived psychological wellbeing, where it was enhanced when massage was administered at rest, and during recovery form exercise. None of the studies propose an overall mechanism. However, it is postulated that the mechanism/mechanisms would either be a decrease in circulating catecholamine, an increase in endogenous opioids (e.g. beta endorphin), or a shift from right asymmetry towards left frontal asymmetry, which is indicative of positive mood enhancement.

Vibratory massage also had a positive effect on perception of feeling compared to Rest, but interestingly there was a marked difference between VM and MM, where MM had the greater effect. This response is consistent with Diego, Field, Sanders & Hernandez-Reif (2004) who reported that the effect of vibratory massage on psychological and physiological variables were enhanced compared with Rest, but not as positive as manual massage.

7.7.2 Perceived pain: During a preliminary research (Jones & Cotterrell, 1999), pain was measured using an interval perception scale (Tiidus & Ianuzzo, 1983) following a WAnT. The results were inconclusive, suggesting that the 30sec exercise bout was too short to cause sufficient measurable muscle damage. Furthermore, it was anticipated that a bout of aerobic exercise would not cause any appreciable degree of muscle damage, and consequently would not cause any pain. Therefore, it was decided that an assessment of muscle pain or damage would not be recorded following anaerobic and aerobic exercise during this present study.

In terms of muscle damage as determined by CK release, limb oedema, and muscle strength decrease, it is apparent that MM or VM did not have any physiological benefit following a bout of eccentric arm exercise, when compared to Rest. These findings are consistent with Tiidus & Shoemaker (1995), Smith *et al.*, (1994), Rodenburg, Steenbeek, Schiereck & Bär (1994), and Zainuddin, Newton, Sacco & Nosaka (2005) who found a similar response in both eccentric arm and leg exercise. The only variable which was favourably altered by MM in this respect was perception of feeling. Therefore, the findings of this study suggest that manual massage is beneficial at positively enhancing mood following a bout of eccentric exercise, but from an applied sports science stance, athletes who use manual massage should be aware that there are limited positive physiological responses during recovery.

In respect of vibratory massage, the manufacturers of the G5® vibratory massage machine claim in their product literature that the machine can theoretically close neural pain gates, thus ameliorating or eliminating pain. During this present study, which is the first investigation to study the effects of VM on acute pain associated with eccentric exercise, VM decreased perception of pain compared to MM and R throughout the 120hrs monitoring period. However, as previously stated this effect does not appear to be mediated through an obvious decrease in muscle damage, or decreased oedema, or by muscle strength recovery.

The mechanism by which massage enhances this decrease the VM on acute pain following muscle injury has yet to be elucidated. As stated in Chapter 6, the changes evident in perception of pain for VM would be expected to be a result of either an increase in Meissner's corpuscle and Pacinian corpuscles receptors activity, a decrease in substance P release, or a decrease in alpha motorneuron excitability.

Although this study has shown that the perception of pain for VM was consistently lower when compared to Rest and MM, determination of which mechanism or mechanisms were beyond the scope of the study. However, it would prudent be to assume that the stimulation of the Meissner's corpuscle and Pacinian corpuscles receptors is the most likely mechanism by which pain is ameliorated or withdrawn.

The perception of pain data presented here are also consistent with the findings of Ottoson, Ekblom & Hasson, (1981); Sherer, Clelland, O'Sullivan, Doleys & Canan, (1986); Lundeburg, (1986); and Cardinal & Wakeling, (2005) who proposed that vibratory massage applied at 60-100Hz was capable of ameliorating and/or eliminates acute pain.

Despite the positive response of VM at reducing pain, the implications and practical application should be considered with caution. Pain is normally an indication of injury; however if an athlete has no pain, but has compromised muscle strength, decreased range of motion and increased limb circumference, then this puts a joint under pressure. The joint would be unable to stabilise as normal, thus leading to further injury. To this end, vibratory massage administered during the initial stages following eccentric exercise should, in the view of this study, be contraindicated.

With regard to an interaction between the psychological and physiological response exerted by massage, it is evident that the perception of feeling results correlated highly with physiological variables, particularly when the effect of massage following anaerobic were studied. PoF correlated highly with diastolic pressure and blood lactate concentration, indicating that as BLa was at its highest and DBP was at its lowest, perception of feeling decreased. This response was reversed during the subsequent recovery period when DBP and BLa concentration returned to baseline level.

7.8 Is the physiological and psychological response of manual and vibratory massage administered at rest similar to the response when massage is administered during recovery from exercise?

This is the first series of investigations to compare the effects of manual and vibratory massage at rest to its effects during recovery from exercise. It is apparent from the five investigations presented in this study that the massage conditions have a similar effect during both physical states.

At rest, leg massage was administered for 10mins and 30mins. The results suggest that massage decreased cardiac sympathetic drive and increased parasympathetic drive (deemed for the HRV data); which decreased heart rate, rate pressure product and respiratory rate; had no effect on limb blood flow and metabolic rate; but enhanced perception of feeling. These aforementioned responses were duplicated during leg massage recovery from aerobic and anaerobic exercise. For example, the mean percentage difference between Rest and MM for rate pressure product at rest was 12.7%, which accords with a mean difference of 12.2% during recovery from exercise. Similarly, at rest, the percentage difference between 30mins Rest and MM for respiratory rate was 9.33% which accords with a 9.84% difference following 30mins recovery from exercise. In addition, the mean percentage difference between Rest and VM for rate pressure product at rest was 12.2%, which accords with a mean difference of 11.1% during recovery from exercise. Similarly, at rest, the percentage difference between Rest and VM for heart rate was 6.03% which accords with a mean 6.69% difference following recovery from exercise.

These examples confirm that the physiological and psychological effects of manual and vibratory massage are consistent when administered at rest, and during recovery from exercise.

7.9 Is there any difference in the physiological and psychological response between manual and vibratory massage?

There is very little published data to substantiate the effectiveness of vibratory massage as a method of recovery from intense exercise. The majority of research data concentrates on its use to alleviate back pain (Lundburg *et el.*, 1984 and (Cafarelli, Sim, Carolan & Liebesman, 1990). High amplitude and frequency vibration has been shown to have a negative effect on the human body, altering blood flow, also causing damage to tendons, ligaments and bone (Cardinale & Wakeling, 2005). However, research data suggests that low frequency and low amplitude vibration is considered a safe way of passively exercising the body's musculoskeletal structures. Moreover, it has been shown to produce increases in muscle strength and power (Cardinale & Bosco, 2003). Furthermore, Diego, Field, Sander & Hernandez-Reif (2004) showed that vibratory massage causes a decrease in anxiety and stress (measured with an electroencephalograph) and a lowering of blood pressure. Furthermore, Field (1998) recommended that any future research which attempts to elucidate the physiological and psychological effects of vibratory massage should compare the method to manual massage in order to gain an accurate comparison.

The manufactures of the vibratory massage machine used in this present study claim that the apparatus will have a similar physiological and psychological effect to that of manual massage. However, they do not currently have any empirical research data to substantiate their claims. Furthermore, it has been suggested that the machine does not aim to replace manual massage, but should be used as an alternative.

This study has shown that both MM and VM had similar responses for the majority of physiological functions measured during this study; however, in the majority of cases the response for VM was less pronounced. For example, in Chapter 3, when a 30min leg massage was administered at rest, on completion of 30min leg massage, HR for VM was 65.4±7.7bpm contrasting with 63.7±7.4bpm for MM. Furthermore, RPP, LF:HFratio and RR were all higher following VM compared to MM. This response on cardiovascular parameters also occurred following exercise, and on completion of the 45min leg massage, blood lactate concentration was lower for VM compared to Rest, but was not as low as MM.

There were a few exceptions where the response of vibratory massage was greater than that of manual massage. Skin temperature was higher for VM than MM; however, as discussed previously, this effect does not appear to have any benefit. This is because it is merely a consequence of the greater friction between the G5® applicators and the treated skin (Chapter 4 & 5). The only instance where VM had a greater beneficial effect was following a bout of eccentric exercise. In direct contrast to MM, perception of pain for VM had been eliminated pain by 72hrs. This effect had an influence on perception of feeling in the first 24hrs, which was higher than MM.

Therefore, the manufacturers claims regarding the G5® vibratory massage machine are in part substantiated, in that vibratory massage does has a similar effect to its manual equivalent. However, the physiological basis for these similarities between MM and VM are unclear, and therefore warrant further more detailed investigation.

7.10 Overall study conclusions

In conclusion, the results of the present study accepts the proposed null hypothesis that mechanical vibratory massage (VM) is equally as effective as manual massage when administered at rest, and during recovery from aerobic, anaerobic and eccentric exercise. This was confirmed by the similar/equivalent effects on cardiac autonomic activity, blood pressure, respiration and perception of feeling. In addition, the results also confirm that (VM) has a greater effect on perception of pain following eccentric exercise suggesting a superior effect on neural modulation of pain perception.

7.11 Directions of future research

There are a number of areas of research into the physiological and psychological effects of massage which were outside the scope of this study, but are worthy of future investigation. These are:-

This study is the first to compare the physiological effects of manual and vibratory massage when administered at rest and during recovery from exercise. Further investigations are essential in order to fully compare the response between the two forms of massage. Such studies would in turn substantiate claims and inform vibratory massage machine manufacturers, in order that they can revise their promotional literature

Apart from the information presented in this study, there is paucity of research into the effects of vibratory massage on physiological, mechanical and psychological functions. An area of particular interest, which warrants more detailed investigation is the effect of vibratory massage on acute and chronic pain. Since the original investigation by Lundberg (1986), there has been virtually no empirical research into the beneficial effects of vibratory massage on pain. Such research is required to ascertain and quantify any changes in pain following the administration of vibratory massage, and to investigate which types of painful conditions respond best.

This study has shown that leg massage alters cardiac autonomic activity, by increasing parasympathetic activity. Of the three investigations presented, the shortest time period of leg massage was 10mins (calf massage). Future research should investigate the minimum time required to initiate a sympathovagal shift, quantified by an alteration in HRV, heart rate, blood pressure and rate pressure product. In addition, cardiac autonomic activity should be investigated to ascertain the beneficial effects of massage at reducing stress, particularly in respect of diseased patients.

Delaney, Leong, Watkins & Brodie (2002) acknowledged that a limitation of their study was that they did not account for the touch interaction between the therapist and subject. Touch has been shown to decrease tension, heart rate and mean blood pressure, thus indicating a parasympathetic response (Wendler, 2003; and McCaffrey & Taylor, 2005). Therefore, future studies should include comparisons between therapeutic touch and manual massage to ascertain whether the psychophysiological effects of massage is merely because of touch, or as consequence of the massage techniques.

Exercise overtraining occurs when an athletes training duration and intensity is greater than the capacity to adapt, leading to performance deterioration and detrimental health effects. This has been associated with increased serum cortisol and with a decrease in both total and free testosterone (Costa, Jones, Lamb, Coleman & Williams, 2005). Massage has been shown to decrease serum coritsol in premature infants (Beider & Moyer, 2007), women with anorexia (Hart *et al.*, 2001), and patients undergoing chemotherapy (Stringer, Swindell & Dennis, 2008). Therefore, there is an opportunity for future studies to investigate the effect of administering a regular massage regime to athletes suffering from overtraining syndrome, including those athletes who are undergoing periods of intense exercise during as part of their periodised training regime.

This study, along with many other empirical research investigations, has so far focused on the effect of massage on physiological recovery post exercise. However, there is paucity of information on the effects of massage administered pre exercise.

Future research should focus on the effects of administering massage pre exercise, or combining massage with an active warm up, thus promoting an ergogenic physiological response, and enhancing pre-event psychological alertness.

Popular opinion would suggest that there is disparity between the views of the general public and athletic community, and the evidence emerging from this empirical research; regarding the beneficial physiological effects of massage. This disparity appears to have arisen as a direct result of misguided information presented in textbooks dedicated to massage. Therefore, there is an opportunity for future studies to focus on this aspect, in an attempt to address these issues.

REFERENCES

Acolet, D., Modi, N., Giannakoulopoulos, X., Bond, C., Weg, W., Clow, A. & Glover, V. (1993). Changes in plasma cortisol and catecholamine concentrations in response to massage in preterm infants. *Archives of Disease in Childhood*, 68, 29-31.

Akselrod, S., Gordon, D., Madwed, J.B., Snidman, N.C., Shannon, D.C. & Cohen, R.J. (1985). Hemodynamic regulation: investigation by spectral analysis. *American Journal of Physiology*, 249, H867-H875.

Albury, M.E. (1934a). Physical therapy and the lymphatics. *The Journal of the Chartered Society of Massage and Medical Gymnastics*, 20(4), 92-93.

Albury, M.E. (1934b). The lymphatic system and its functions. *The Journal of the Chartered Society of Massage and Medical Gymnastics*, 20(4), 94-95.

Allen, D.G. & Westerblad, H. (2001). Role of phosphate and calcium stores in muscle fatigue. *Journal of Physiology*, 563(3), 657-665.

Anon (1992). Vibration therapy for pain. *The Lancet*, 339, 1513-1514.

Aourell, M., Skoog, M. & Carleson, J. (2005). Effects of Swedish massage of blood pressure. *Complementary Therapies in Clinical Practice*, 11(4), 242-247.

Archer, P.A. (2006). *Introduction to Therapeutic Massage in Athletics*. London: Lippincott Williams & Wilkins.

Armstrong, R. (1990). Initial events in exercise-induced muscular injury. *Medicine and Science in Sports and Exercise*, 22(4), 429-435.

Bahr, R., Grønnerød, O. & Sejersted, O.M. (1992). Effect of supramaximal exercise on excess post-exercise O_2 consumption. *Medicine and Science in Sports and Exercise*, 24(1), 66-71.

Baldwin, K.M., Hooker, A.M. & Herrick, R.E. (1978). Lactate oxidative capacity in different types of muscle. *Biochemical and Biophysical Research Communications*, 83, 151-157.

Bale, P., & James, H. (1991). Massage, warm-down and rest as recuperative measures after short term intense exercise. *Physiotherapy in Sport*, 13, 4-7.

Balke, B., Anthony, J., & Wyatt, F. (1989). The effects of massage treatment on exercise fatigue. *Clinical Journal of Sports Medicine*, 7, 189-197.

Barlow, U.A., Chung, V. & Stewart-Brown, S. (2006). Massage intervention for promoting mental and physical health in infants aged under six months. *The Cochrane Library*, 3, 1-28.

Bar-Or, O. (1987). The Wingate Anaerobic Test. An update on methodology, reliability and validity. *Sports Medicine*, 4, 381-394.

Barr, J.S. & Taslitz, N. (1970). The influence of back massage on autonomic functions. *Physical Therapy*, 50, 1679-1691.

Batavia, M. (2004). Contraindications for therapeutic massage: do sources agree? *Journal of Bodywork and Movement Therapies*, 8(1), 48-57.

Beary, J.F., Benson, H. & Klemchuk, H.P. (1974). A simple psychophysiological technique which elicits the hypometabolic changes of the relaxation response. *Psychosomatic Medicine*, 36(2), 115-120.

Beelen, A. & Sargent, A.J. (1991). Effect of lowered muscle temperature on the physiological response to exercise in man. *European Journal of Applied Physiology*, 63,

387-392.

Beider, S. & Moyer, A. (2007). Randomized controlled trials of paediatric massage: A review. *Evidence-based Complementary and Alternative Medicine*, 4(1), 23-34.

Belcastro, A.N., & Bonen, A. (1975). Lactic acid removal rates during controlled and uncontrolled recovery exercise. *Journal of Applied Physiology*, 39(6), 932-937.

Bell, A.J. (1964). Massage and the physiotherapist. *Physiotherapy*, 50(12), 406-408.

Bender, T., Nagy,G., Barna, I., Tefner, I., Kádas, E. & Géher, P. (2007). The effect of physical therapy on beta-endorphin levels. *European Journal of Applied Physiology*, 100, 371-382.

Benjamin, P.J. (1993). Massage therapy in the 1940's and the College of Swedish Massage in Chicago. *Massage Therapy Journal*, 32(4), 57-62.

Bernardi, L., Bianchini, B., Spadacini, G., Leuzzi, S., Valle, F., Marchesi, E., Passino, C., Calciati, A., Viganó, M., Rinaldi, M., Martinelli, L., Finardi, G. & Sleight, P. (1995). Demonstrable cardiac reinnervation after human heart transplantation by carotid baroreflex modulation of RR interval. *Circulation*, 92(10), 2895-2903.

Bigger, J.T., Fleiss, J.L., Rolnitzky, L.M. & Steinman, R.C. (1993). The ability of several short-term measures of RR variability to predict mortality after myocardial infarction. *Circulation*, 88(3), 927-934.

Billhult, A. & Dahlberg, K. (2001). A meaningful relief from suffering experiences of massage in cancer care. *Cancer Nursing*, 24(3), 180-184.

Binzoni, T. & Delpy, D. (2001). Local temerpature changes and human skeletal muscle metabolism. *Journal of Physiological Anthropolog and Applied Human Science*, 20(3), 159-174.

Bolanowski, S.J. & Zwislocki, J.J. (1984a). Intensity and frequency characteristic of pacinian corpuscles I. Action potentials. *Journal of Neurophysiology*, 51(4), 793-811.

Bolanowski, S.J. & Zwislocki, J.J. (1984b). Intensity and frequency characteristic of pacinian corpuscles II. Receptor potentials. *Journal of Neurophysiology*, 51(4), 812-830

Bonen, A., & Belcastro, A.N. (1976). Comparison of self-selected recovery methods on lactic acid removal rates. *Medicine in Sport and Exercise*, 8(3), 176-178.

Bonnemeier, H., Wiegand, U.K.H., Brandes, A., Kluge, N., Katus, H.A., Richardt, G. & Potratz, J. (2003). Circadian profile of cardiac autonomic nervous modulation in healthy subjects. Differing effects of aging and gender on Heart Rate Variability. *Journal of Cardiovascular Electrophysiology*, 14(8), 791-799.

Boone, T. & Cooper, R. (1995). The effect of massage on oxygen consumption at rest. *The American Journal of Chinese Medicine*, 23(1), 37-41.

Boone, T., Cooper, R. & Thompson, W.R. (1991). A physiological evaluation of the sports massage. *Athletic Training*, 26, 51-54.

Boone, T., Tanner, M. & Radosevich, A. (2001). Effects of a 10minute back rub on cardiovascular responses in healthy subjects. *The American Journal of Chinese Medicine*, 29(1), 47-52.

Borg, G. (1998). *Borg's Perceived exertion and pain scales*. Leeds: Human Kinetics.

Boutcher, Y.N. & Boutcher, S.H. (2005). Limb vasodilatory capacity and venous capacitance of trained runners and untrained males. *European Journal of Physiology*, 95(1), 83-87.

Braun, H.P. (1987). Validation of the Reflotron. *Clinical Chemistry*, 33(7), 988.

Brenner, K.M., Thomas, S. & Shephard, R.J. (1997). Spectral analysis of heart rate variability during heat exposure and repeated exercise. *European Journal of Applied Physiology*, 76(2), 145-157.

Brooks, G.A. (1975). *Lactate: Glycolytic end product and oxidative substrate during exercise in mammals - "The lactate shuttle".* In R. Giles (Ed.) Comparative Physiology and Biochemistry: Current Topics and Trends. New York: Springer Verlag.

Brooks, G.A. (1986). The lactate shuttle during exercise and recovery. *Medicine and Science in Sports and Exercise*, 18(3), 360-368.

Brooks, G.A. (2000). Intra- and extra-cellular lactate shuttles. *Medicine and Science in Sports and Exercise*, 32(4), 258-264.

Brooks, G.A., & Gaesser, G.A. (1980). End points of lactate and glucose metabolism of lactic acid after exercise. *Journal of Applied Physiology*, 49(6), 1057-1069.

Brooks, G.A., Dubouchaud, H., Brown, Sicurello, J.P. & Butz, C.E. (1999). Role of mitochondrial lactate dehydrogenase and lactate oxidation in the intercellular lactate shuttle. *Proceedings of the National Academy of Sciences of the USA*, 96, 1129-1134.

Bruce-Low, S., Cotterrell, D. & Jones, G.E. (2006). Heart Rate Variability during high ambient heat exposure. *Aviation, Space and Environmental Medicine*, 77(9), 915-920.

Bulbulian, R., Darabos, B., & Nauta, S. (1987). Supine rest and lactic acid removal following maximal exercise. *Journal of Sports Medicine*, 27(2), 151-157.

Burovykh, A.N., Samtsova, A.V., & Manuilov, I.A. (1976). An investigation of the effect of individual variants of sports massage on muscular blood circulation. *Soviet Sports Review*, 24, 197-200.

Cable, T. (2001). Cardiovascular Function. In R. Eston & T. Reilly (Eds.), *Kinanthropometry and exercise physiology laboratory manual: tests, procedures, and data* (pp. 117-135). Oxford: Taylor & Francis Group Ltd.

Cady, S.H. & Jones, G.E. (1997). Massage therapy as a workplace intervention for reduction of stress. *Perceptual and Motor Skills*, 84(1), 157-158.

Cafarelli, E. & Flint, F. (1992). The role of massage in preparation for and recovery from exercise. *Sports Medicine*, 14(1), 1-9.

Cafarelli, E., Sim, J., Carolan, B., & Liebsman, J. (1990). Vibratory massage and short-term recovery from muscular fatigue. *International Journal of Sports Medicine*, 11(6), 474-478.

Caldwell, E. (2003). *Understanding Massage*. Gloucestershire: First Stone Publishing.

Callaghan, M.J. (1993). The role of massage in the management of the athlete: A review. *British Journal of Sports Medicine*, 27(1), 28-33.

Calvert, R.N. (2002a). *The History of Massage: An Illustrated Survey from Around the World.* Rochester: Inner Traditions Bear and Company.

Calvert, R.N. (2002b). Pages From History: Vibration and Vibrators, Part One. *Massage Magazine*, 98.

Calvert, R.N. (2002c). Pages From History: Vibration and Vibrators, Part Two. *Massage Magazine*, 99.

Cambron, J.A., Dexheimer, J. & Coe, P. (2006). Changes in blood pressure after various forms of therapeutic massage: a preliminary study. *The Journal of Alternative and Complementary Medicine*, 12(1), 65-70.

Campbell, R.L. & Langston, W.G. (1995). A comparison of cardiac rate-pressure product and pressure-rate quotient in healthy and medically compromised patients. *Oral Surgery,* *Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, 80(2), 145-152.

Campbell, R.L., Langston, W.G. & Ross, G.A. (1997). A comparison of cardiac rate-pressure product and pressure-rate quotient with Holter monitoring in patients with hypertension and cardiovascular disease: A follow-up report. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, 84(2), 125-128.

Cardinale, M. & Bosco, C. (2003). The effects of vibration as an exercise intervention. *Exercise and Sports Sciences Reviews*, 31(1), 3-7.

Cardinale, M. & Lim, J. (2003). Electromyography activity of vastus lateralis muslec during whole-body vibrations of different frequencies. *Journal of Strength and Conditioning Research*, 17(3), 621-624.

Cardinale, M. & Wakeling, J. (2005). Whole body vibration exercise: are vibrations good for you? *British Journal of Sports Medicine*, 39(9), 585-589.

Cardinale, M., Soiza, R.L., Leiper, J.B., Gibson, A. & Primrose,W.R. (2008). Hormonal responses to a single session of whole body vibration exercise in elderly individuals. *British Journal of Sports Medicine*, Aprl 15th.

Carlsöö, S. (1982). The effect of vibration on the skeleton, joints and muscles. *Applied Ergonomics*, 13(4), 251-258.

Carrier, E.B. (1922). The reaction of the human skin capillaries to drugs and other stimuli. *American Journal of Physiology*, 61, 528-547.

Cash, M. (1996). *Sport and Remedial Massage Therapy*. London: Ebury Press.

Cassar, M.P. (2004). *Handbook of Clinical Massage: A complete guide for students and professionals* (2nd ed.). Oxford: Elsevier Health Sciences.

Chandenra, T., Yeates, D.B. & Wong, L.B. (2003). Heart rate variability analysis - current and future trends. *Global Healthcare: Business Briefing*, 1-4.

Chang, R.K., Qi, N., Larson, J., Rose-Gottron, C. & Cooper, D. (2005). Comparison of Upright and Semi-Recumbent Postures for Exercise Echocardiography in Healthy Children. *American Journal of Cardiology*, 95(7), 918-921.

Chen, T.C. (2006). Variability in muscle damage after eccentric exercise and repeated bout effect. *Research Quarterly for Exercise and Sport*, 77(3), 362-371.

Chleboun, G.S., Howell, J.N., Conatser, R.R. & Giesey, J.J. (1998). Relationship between muscle swelling and stiffness after eccentric exercise. *Medicine and Science in Sports and Exercise*, 30(4), 529-535.

Chuah, S.S., Woolfson, P.I., Pullan, B.R. & Lewis, P.S. (2004). Plethysmography without venous occlusion for measuring forearm blood flow: comparison with venous occlusive method. *Clinical Physiology and Functional Imaging*, 24(5), 296-303.

Clarkson, P.M., Nosaka, K. & Braun, B. (1992). Muscle function after exercise induced muscle damage and rapid adaptation. *Medicine and Science in Sports and Exercise*, 24(5), 512-520.

Clayton, E.B. (1915) Massage and the war. *The Lancet*, 4816, 1369.

Cleak, M.J. & Eston, R.G. (1992). Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. *British Journal of Sports Medicine*, 26(4), 267-272.

Coats, A.J., Conway, J., Isea, J.E., Pannarale, G., Sleight, P. & Somers, V.K. (1989). Systemic and forearm vascular resistance changes after upright bicycle exercise in man. *Journal of Physiology*, 413(1), 289-298.

Connolly, D.A.J, Sayers, S.P. & McHugh, M.P. (2003). Treatment and prevention of delayed onset muscle soreness. *Journal of Strength and Conditioning Research*, 17(1),

197-208.

Corley, M., Ferriter, J., Zeh, J & Gifford, C. (1995). Psychological and physiological effects of back rubs. *Applied Nursing Research*, 8(1), 39-43.

Cosca, D.D. & Navazio, F (2007). Common problems in endurance athletes. *American Family Physician*, 76(2), 237-244.

Costa, R.J.S., Jones, G.E., Coleman, R., Lamb, K.L. & Williams, J.H.H. (2005). The effects of a high carbohydrate diet on cortisol and salivary immunoglobulin A (s-IgA) during a period of increase exercise workload amongst Olympic and Ironman Triathletes. *International Journal of Sports Medicine*, 26(10), 880-885.

Craig, J., Bradley, J. & Walsh, D., Baxter, G.D. & Allen, J.M. (1999). Delayed onset muscle soreness: lack of effect of therapeutic ultrasound in humans. *Archives of Physical Medicine and Rehabilitation*, 80(3), 318-323.

Cummins, T.R., Sheets, P.L. & Waxman, S.G. (2007). The roles of sodium channels in nociception: Implications for mechanisms of pain. *Pain*, 131(3), 243-257.

Cuthbertson, D.P. (1932). The effect of massage on metabolism of normal individuals. *Quarterly Journal of Medicine*, 3, 387-400.

Cuthbertson, D.P. (1933). Effect of massage on metabolism. A survey. *Glasgow Medical Journal*, 2, 200-213.

Davidson, R.J. (2000). Affective style, psychopathology, and resilience: Brain mechanisms and plasticity. *American Psychologist*, 55, 1196-1214.

DeDomenico, G. (2007). *Beard's Massage: Principles and Practice of Soft Tissue Manipulation* (5th ed.). Philadelphia: W.B. Saunders Elsevier.

Delaney, J.P.A. & Brodie, D.A. (2000). Effects of short-term psychological stress on the time and frequency domains of heart rate variability. *Perceptual and Motor Skills*. 91(2), 515-524.

Delaney, J.P.A., Leong, K.S & Brodie, D.A. (2001). Short-term power spectral analysis of heart rate variability: a comparison of the method of data acquisition and analysis. *European Journal of Clinical Investigation*, 31 (Suppl. 1): 2 (Abstract).

Delaney, J.P.A., Leong, K.S., Watkins, A. & Brodie D.A. (2002). The short term effects of myofascial trigger point massage therapy on cardiac autonomic tone in healthy subjects. *Journal of Advanced Nursing*, 37(4), 364-371.

De-Roiste, A. & Bushnell, I.W.R. (1996). Tactile stimulation: short and long term benefits for preterm infants. *The British Journal of Developmental Psychology*, 41, 41-53.

Diego, M.A., Field, T., Sanders, C. & Hernandez-Reif, M. (2004). Massage therapy of moderate and light pressure and vibrator effects on EEG and heart rate. *International Journal of Neurosciences*, 114(1), 31-45.

Dishman, J.D. & Bulbulian, R. (2001). Comparison of effects of spinal manipulation and massage on motoneuron excitability. *Electromyography and Clinical Neurophysiology*, 41(2), 97-106.

Dishman, R.K., Nakamura, Y., Garcia, M.E., Thompson, R.W., Dunn, A.L. & Blair, S.N. (2000). Heart rate variability, trait anxiety, and perceived stress among physically fit men and women. *International Journal of Psychophysiology*, 37(2), 121-133.

Doering, T.J., Fieguth, H.G., Steuernagel, B., Brix, J., Konitzer, M., Schneider, B. & Fischer, G.C. (1999). External stimuli in the form of vibratory massage after heart or lung transplantation. *American Journal of Physical Medicine*, 78(2), 108-110.

Dolezal, B., Potteiger, J., Jacobsen, D. & Benedict, S.H. (2000). Muscle damage and resting metabolic rate after acute resistance exercise with an eccentric overload. *Medicine and Science in Sports and Exercise*, 32(7), 1202-1207.

Dolgener, F.A. & Marien, A. (1993). The effect of massage on lactate disappearance. *Journal of Strength and Conditioning Research*, 7, 159-162.

Donnelly, A.E., McCormick, K., Maughan, R.J., Whiting, P.H. & Clarkson, P.M. (1988). Effects of a non-steroidal anti-inflammatory drug on delayed onset muscle soreness and indices of damage. *British Journal of Sports Medicine*, 22(1), 35-38.

Donovan, C.M. & Brooks, G.A. (1983). Endurance training effects lactate clearance, not lactate production. *American Journal of Physiology, Endocrinology and Metabolism.* 244(1), E83-E92.

Drust, B., Atkinson, G., Gregson, W., French, D. & Binningsley, D. (2003). The effects of massage on intramuscular temperature in the vastus lateralis in humans. *International Journal of Sports Medicine*, 24, 395-399.

Dubrovsky, V.I. (1982). Changes in muscle and venous blood flow after massage. *Soviet Sports Review*, 4, 56-57.

Dudley, G., McGrath, K.N. & Pheley, A.M. (2003). Length of stay and medication use in hysterectomy patients treated with a single massage treatment. *Journal of Bodyworks and Movement Therapies*, 7(4), 222-227.

Duffield, R., Dawson, B., Pinnington, H.C. & Wong, P. (2004). Accuracy and reliability of a Cosmed K4b2 portable gas analysis system. *Journal of Science and Medicine in Sport*, 7(1), 11-22.

Eisenmann, J.C., Brisko, N., Shadrick, D. & Welsh, S. (2003). Comparative analysis of the Cosmed Quark b2 and K4b2 gas analysis systems. *Journal of Sports Medicine and Physical Fitness*, 43(2), 150-155.

Ekberg, D.L. (1997). Sympathovagal balance: a critical approach. *Circulation*, 86, 3224-3232.

Ernst, E. (1998). Does post-exercise massage treatment reduce delayed onset muscle soreness? A systematic review. *British Journal of Sports Medicine*, 32(3), 212-214.

Ernst, E. (2003). The safety of massage therapy. *Rheumatology*, 42(9), 1101-1107.

Erskine, J., Smillie, I., Leiper, J., Ball, D. & Cardinale, M. (2007). Neuromuscular and hormonal responses to a single session of whole body vibration exercise in healthy young men. *Clinical Physiology and Functional Imaging*, 27(4), 242-248.

Eston, R.G. & Peters, D. (1999). Effects of cold water immersion on the symptoms of exercise induced muscle damage. *Journal of Sports Science*, 17(3), 231-238.

Eston, R.G., Finney, S., Baker, S. & Baltzopoulos, V. (1996). Muscle tenderness and peak torque changes after downhill running following a prior bout of isokinetic eccentric exercise. *Journal of Sports Science*, 14(4), 291-299.

Fakouri, C. & Jones, P. (1987). Relaxation Rx: Slow stroke back rub. Journal *of Gerontological Nursing*, 13(2), 32-35.

Faria, I.E., & Cavanagh, P.R. (1978). *The Physiology and Biomechanics of Cycling*. New York: John Wiley.

Farr, T,. Nottle, C., Nosaka, K. & Sacco, P. (2002). The effects of therapeutic massage on delayed onset muscle soreness and muscle function following downhill walking. *Journal of Science and Medicine in Sport*, 5(4), 297-307.

Fassett, F.J. (1904). Systems of mechanical therapeutics: A comparative study. *The Journal of the American Osteopathic Association*, 3(7), 210-218.

Ferber, S.G., Kuint, J., Weller, A., Feldman, R., Dollberg, S., Arbel, E. & Kohelet, D. (2002). Massage therapy by mothers and trained professionals enhances weight gain in preterm infants. *Early Human Development*, 67(1-2), 37-45.

Field, T., Hernandez-Reif, M., Diego, M., Schanburg, S. & Kuhn, C. (2005). Cortisol decreases and serotonin and dopamine increase following massage therapy. *International Journal of Neuroscience, 115*, 1397-1413.

Field, T.M. (1998). Massage therapy effects. *American Psychologist*, 53(12), 1270-1281.

Field, T.M., Hernandez-Reif, M., Hart, S., Theakston, H., Schanberg, S. & Kuhn, C. (1999). Pregnant women benefit from massage therapy. *Journal of Psychosomatic Obstretics and Gynecology*, 20, 31-38.

Field, T.M., Diego, M., Cullen, C., Hernandez-Reif, M., Sunshine, W. & Douglas, S. (2002). Fibromyalgia pain and substance P decrease and sleep improves after massage therapy. *Journal of Clinical Rheumatology*, 8(2), 72-76.

Field, T.M., Diego, M., Dieter, J., Hernandez-Reif, M., Schanberg, S. & Kuhn, C., Yando, R. & Bendell, D. (2004). Prenatal depression effects on the fetus and the newborn. *Infant Behaviour and Development*, 27, 216-229.

Field, T.M., Diego, M., Hernandez-Reif, M. & Shea, J. (2007). Hand arthritis pain is reduced by massage therapy. *Journal of Bodywork and Movement Therapies*, 11(1), 21-24.

Field, T.M., Schanberg, S.M., Scafidi, F., Bauer, C.R., Vega-Lahr, N. & Garcia, R. (1986). Tactile-kinesthetic stimulation effects on preterm neo-nates. *Paediatrics*, 77(5), 654-658.

Fridén, J & Lieber, R.L. (2001). Serum creatine kinase is a poor predictor of muscle function after injury. *Scandinavian Journal of Medicine and Science in Sports*, 11(2), 126-127.

Fridén, J., Sfakianos, P.N., Hargen, A.R. & Akeson, W.H. (1988). Residual muscular swelling after repetitive eccentric contractions. *Journal of Orthopaedic Research*, 6(4), 493-498.

Fronek, A., Goldman, M. & Fronek, K. (1998). The effect of compression on venous haemodynamics assessed by quantitative photoplethysmography., *Phlebology*, 13, 98-101.

G5 Europe (2008). Physical and Respiratory Therapy Systems. Retrieved from Physiothérapie Générale France website http://uk.g5europe.com/catalogue01.aspx?id_cat=2

Gallios, P. (1984). Neurophysiologic and respiratory changes during the practice of relaxation techniques. *Encephale*, 10(3):139-144.

Gammon, G.D. & Starr, I. (1940). Studies on the relief of pain by counter-irritation. *Journal of Clinical Investigation*, 20, 13-20.

Ganong, W.F. (2003). *Review of medical physiology*. London: McGraw-Hill.

Gilman, S. (2002). Joint position sense and vibration sense: anatomical organisation and assessment. *Journal of Neurology, Neurosurgery and Psychiatry*, 73(5), 473-477.

Gisolfi, C.G., Robinson, S., & Turrell, S. (1966). Effects of aerobic work performed during recovery from exhausting work. *Journal of Applied Physiology*, 21(6), 1767-1772.

Gladden, L.B. (2000). Muscle as a consumer of lactate. Medicine and Science in Sports and Exercise, 32(4), 764-771.

Goats, G.C. (1994). Massage: the scientific basis of an ancient art. Physiological and therapeutic effects. *British Journal of Sports Medicine*, 28(3), 153-157.

Godfrey, H. (2005a). Understanding pain, part 1: physiology of pain. *British Journal of*

Nursing, 14(16), 846-852.

Godfrey, H. (2005b). Understanding pain, part 1: pain management. *British Journal of Nursing*, 14(16), 904-909.

Gohar, O. (2005). Contribution of ion channels in pain sensation. *Modulator*, 19, 9-13.

Goldberg, J., Sullivan, S.J. & Seabourne, D.E. (1992). The effect of two intensities on H-reflex amplitude. Physical Therapy, 72(6), 449-457.

Golden, C.L. & Dudley, G.A. (1992). Strength after bouts of eccentric or concentric actions. *Medicine and Science in Sports and Exercise*, 24(8), 926-933.

Goldstone, L.A. (1999). From orthodox to complementary: the fall and risew of massage, with specific reference to orthopaedic and rheumatology nursing. *Journal of Orthopaedic Nursing*, 3, 152-159.

Goldstone, L.A. (2000). Massage as an orthodox medical treatment past and present. *Complementary Therapies in Nursing and Midwifery*, 6, 169-175.

Gregor, S.M., Perell, K.L., Rushatakantovit, S., Miyamoto, E., Muffoletto, R. & Gregor, R.J. (2002). Lower extremity general muscle moment patterns in healthy individuals during recumbent cycling. *Clinical Biomechanics*, 17(2), 123-129.

Gregson, W., Drust, B., Batterham, A. & Cable, N. (2002). The effects of pre-warming on the metabolic and thermoregulatory responses to prolonged submaximal exercise in moderate ambient temperatures. *European Journal of Physiology*, 86(6), 526-533.

Guieu, R., Tardy-Gervet, M.F. & Giraud, P. (1993). Substance P-like immunoreactivity and analgesic effects of vibratory stimulation on patients suffering from chronic pain. *Canadian Journal of Neurological Sciences*, 20(2), 138-141.

Gupta, S., Goswami, A., Sadhukhan, A.K., & Mathur, D.N. (1996). Comparative study of lactate removal in short term massage of extremities, active recovery and passive recovery period after supramaximal exercise sessions. *International Journal of Sports Medicine*, 17(2), 106-110.

Habel, U., Klein, M., Kellermann, T., Shah, N.J & Schneidera, F. (2005). Same or different? Neural correlates of happy and sad mood in healthy males. *Neuroimage*, 26(1), 206-214.

Hakansson, N.A. & Hull, M.L. (2005). Functional roles of the leg muscles when pedalling in the recumbent versus the upright position. *Journal of Biomechanical Engineering*, 127(2), 301-310.

Haker, E., Egekvist, H. & Bjerring, P. (2000). Effect of sensory stimulation (acupuncture) on sympathetic and parasympathetic activities in healthy subjects. *Journal of the Autonomic Nervous System*, 79(1), 52-59.

Hale. T., Armstrong, N., Hardman, A., Jakeman, P., Sharp, C. & Winter, E. (1996). *Position statement on the Physiological Assessment of the Elite Competitor*. Leeds: British Association of Sports Science.

Hansen, T.I., & Kristensen, J.H. (1973). Effect of massage, short-wave diathermy and ultrasound upon ^{133}Xe disappearance rate from muscle and subcutaneous tissue in the human calf. *Scandinavian Journal of Rehabilitation Medicine*, 5, 179-182.

Hart, J.M., Swanik, B. & Tierney, R.T. (2005). Effects of sports massage on limb girth and discomfort associated with eccentric exercise. *Journal of Athletic Training*, 40(3), 181-185.

Hart, S., Field, T., Hernandez-Reif, M., Nearing, G., Shaw, S., Schanberg, S., & Kuhn, C. (2001). Anorexia symptoms are reduced by massage therapy. *Eating Disorders*, 9(4), 289-299.

Hausswirth, C., Bigard, J.M. & Le Chevalier, J.M. (1997). The Cosmed K4 telemetry system as an accurate device for oxygen uptake measurements during exercise. *International Journal of Sports Medicine*, 18, 449-453.

Hayes, J. & Cox, C. (1999). Immediate effects of a five-minute foot massage on patients in critical care. *Intensive and Critical Care Nursing*, 15(2), 77-82.

Hayter, T.L., Coombes, J.S., Knez, W.L. & Brancato, T.L. (2005). Effects of electrical muscle stimulation on oxygen consumption. *Journal of Strength and Conditioning Research*, 19(1), 98-101.

Hemmings, B., Smith, M., Graydon, J., & Dyson, R. (2000). Effects of massage on physiological restoration, perceived recovery, and repeated sports performance. *British Journal of Sports Medicine*, 34(2), 109-115.

Hemmings, B.J. (2000a). Psychological and immunological effects of massage after sport. *British Journal of Therapy and Rehabilitation*, 7(12), 516-519.

Hemmings, B.J. (2000b). Sports massage and psychological regeneration. *British Journal of Therapy and Rehabilitation*, 7, 425-429.

Hemmings, B.J. (2001). Physiological, psychological and performance effects of massage therapy in sport: a review of the literature. *Physical Therapy in Sport*, 2, 165-170.

Hendrickson, T.G. (2003). *Massage for orthopaedic conditions*. Lippincott Williams & Wilkins: Philadelphia.

Herminda, R.C., Fernández, J.R., Ayala, D.E., Mojón, A., Alonso, I. & Smolensky, M. (2001). Circadian rhythm of double (rate-pressure) product in healthy normotensive young subjects. *Chronobiology International*, 18(3), 475-489.

Hernandez-Reif, M., Dieter, J., Field, T., Swerdlow, B. & Diego, M. (1998). Migraine headaches are reduced by massage therapy. *International Journal of Neurosciences*, 96, 1-11.

Hernandez-Reif, M., Field, T. & Hart, S. (1999). Smoking cravings are reduced by self-massage. *Preventative Medicine*, 28(1), 28-32.

Hernandez-Reif, M., Field, T., Krasnegor, J., Theakston, H., Hossain, Z. & Burman, I. (2000). High blood pressure and associated symptoms were educed by massage therapy. *Journal of Bodywork and Movement Therapies*, Jan, 31-38.

Hernandez-Reif, M., Field, T., Largie, S., Cullen, C., Beutler, J., Sanders, C., Weiner, W., Rodriguez-Bateman, D., Zelaya, L., Schanberg S. & Kuhn, C. (2002). Parkinson's disease symptoms are differentially affected by massage therapy vs. progressive muscle relaxation: a pilot study. *Journal of Bodywork and Movement Therapies*, 6(3), 177-182.

Hewlett, A.W. & Zwaluwenburg, J.G. (1909). The rate of blood flow in the arm. *Heart*, 1, 87-97.

Hiatt, W.R., Huang, S.Y., Regensteiner, J..G., Micco, A.J., Ishimoto, G., Manco-Johnson, M., Drose, J. & Reeves, J.T. (1989). Venous occlusion plethysmography reduces arterial diameter and flow velocity. *Journal of Applied Physiology*, 66(5), 2239-2244.

High, D.M., Howley, E.T. & Franks, B.D. (1989). The effects of static stretching and warm-up on prevention of delayed-onset muscle soreness. *Research Quarterly for Exercise and Sport*, 60(4), 357-361.

Hilbert, J.E., Sforzo, G.A., and Swensen, T. (2001). The effects of massage on delayed onset muscle soreness. *Medicine and Science in Sports and Exercise*, 33(5), 699.

Hinds, T., McEwan, I., Perkes, J., Dawson, E., Ball, D. & George, K. (2004). Effects of massage on limb and skin blood flow after quadriceps exercise. *Medicine and Science in*

Sports and Exercise, 36(8), 1308-1313.

Hirsch, J.A. & Bishop, B. (1981). Respiratory sinus arrhythmia in humans: How breathing patterns modulates heart rate. *American Journal of Physiology*, 241(4), H620-H629.

Hoeger, W.W.K., Hopkins, D.R., Barette, S.L. & Hale, D.F. (1990). Relationship between repetitions and selected percentages of one repetition maximum: a comparison between untrained and trained males and females. *Journal of Applied Sport Science Research*, 4(2), 47-54.

Hohnloser, S.H., Klingenheben, T., Zabel, M., Sheöder, F. & Hanjörg, J. (1992). Intra-individual reproducibility of heart rate variability. *PACE*, 15, 2211-2214.

Højgaard, M.V., Holstein-Rathlou, N.H., Agner, E. (2005). Reproducibility of heart rate variability, blood pressure variability and baroreceptor sensitivity during rest and head-up tilt. *Blood Pressure Monitoring*, 10(1), 19-24.

Hon, E.H. & Lee, S.T. (1965). Electronic evaluations of the foetal heart rate patterns preceding foetal death: further observations. *American Journal of Obstetric Gynaecology*, 87, 814-827.

Horn , S. & Munafò, M. (1997). *Pain: Theory, research and intervention*. Open University Press: Buckingham.

Hortobágyi, T. & Denahan, T. (1989). Variability in creatine kinase: methodological, exercise and clinically related factors. *International Journal of Sports Medicine*, 10(2), 69-80.

Hovind, H., & Nielsen, S.L. (1974). Effect of massage on blood flow in skeletal muscle. *Scandinavian Journal of Rehabilitation Medicine*, 6, 74-77.

Howatson, G. & Van Someren, K.A. (2003). Ice massage. Effects on exercise induced muscle damage. *Journal of Sports Medicine and Physical Fitness*, 43(4), 500-505.

Howell, J.N., Chleboun, G. & Conatser, R. (1993). Muscle stiffness, strength loss, swelling and soreness following exercise-induced injury in humans. *Journal of Physiology*, 464, 183-197.

Huang, S.T., Chen, G.Y., Lo, H.M., Lin, J.G., Lee, Y.S. & Kuo, C.D. (2005). Increase in the vagal modulation by acupuncture at neiguan point in the healthy subjects. *The American Journal of Chinese Medicine*, 33(1), 157-164.

Hussain, S.T., Smith, R.E., Medbak, S., Wood, R.F.M., & Whipp, B.J. (1996). Haemodynamic and metabolic responses of the lower limb after high intensity exercise in humans. *Experimental Physiology*, 81(2), 173-187.

Jervell, O. (1928). Investigation of the concentration of lactic acid in blood and urine under physiologic and pathologic conditions. *Acta Medica Scandinavica*, Suppl. 24, 1-135.

Jones, A. (1996). Heart rate, lactate threshold and endurance training. *Coaching Focus*, 33, 12-13.

Jones, G. E. (1999). *Comparison of rest, massage and exercise recovery methods on blood lactate removal following a single bout of maximal intensity exercise*. Unpublished Master of Science thesis, University of Chester.

Jones, G.E., & Cotterell, D. (1999). Effect of leg massage on blood lactate removal following a single bout of maximum intensity cycling exercise in humans. *Journal of Physiology*, 518P, 183P.

Jones, G.E., Cotterell, D., Froom, S., Gammon, J.A. & Brucelow, S.S. (2004). The effect of manual and vibratory leg massage following a bout of maximal intensity exercise. *Acta Physiolgica Scandinavia*, 181, A159.

Jones, N.A. & Field, T. (1999). Massage and music therapies attenuate frontal EEG asymmetry in depressed adolescents. *Adolescence*, 34(135), 529-534.

Jönhagen, S., Ackermann, P., Eriksson, T., Saartok, T. & Renström, A.F.H. (2004). Sports massage after eccentric exercise. *American Journal of Sports Medicine*, 32(6), 1499-1503.

Kaada, B. & Torsteinbø, O. (1989). Increase of plasma β-endorphins in connective tissue massage. *General Pharmacology*, 20(4), 487-489.

Kalauokalani, D., Cherkin, D.C., Sherman, K.J., Koepsell, T.D., Deyo, R.A. (2001). Lessons from a trail of acupuncture and massage for low back pain. *Spine*, 26(13), 1418-1424.

Kandel, E.R., Schwartz, J.H. & Jessell, T.M. (2000). *Principles of Neural Science* (4th ed.), New York: McGraw.

Kenney, E., Rejeski, W.J., & Messier, S.P. (1987). Managing exercise distress: The effect of broad spectrum intervention on affect, RPE, and running efficiency. *Canadian Journal of Sports Sciences*, 12, 97-105.

Kerschan-Schindl, K., Grampp, S., Henk, C., Resch, H., Preisinger, E., Fialka-Moser, V. & Imhof, H. (2001). Whole-body vibration exercise leads to alterations in muscle blood volume. *Clinical Physiology*, 21(3), 377-382.

King's College London Archives and Corporate Records Services (2005). Medial Council minutes; TH/M13/1 1929 Apr-1939 http://www.kcl.ac.uk/depsta/iss/archives/collect/1sa70-1.html

Kobayashi, H. (2007). Inter-and intra-individual variations of heart rate variability in Japanese males. *Journal of Physiological Anthropology*, 26(2), 173-177.

Koga, S., Shiojiri, T., Kondo, N. & Barstow, T.J. (1997). Effect of increased muscle temperature on oxygen uptake kinetics during exercise. *Journal of Applied Physology*, 83(4), 1333-1338.

Kondo, K., Matsubara, T., Nakamura, J. & Hotta, N. (2002). Characteristic patterns of circadian variation in plasma catecholamine levels, blood pressure and heart rate variability in Type 2 diabetic patients. *Diabetic Medicine*, 19(5), 359-365.

Kotona, P.G., McLean, M., Dighton, D. & Guz, A. (1982). Sympathetic and parasympathetic cardiac control in athletes and non-athletes at rest. *Journal of Applied Physiology*, 52(6), 1652-1657.

Kowalewski, M.A. & Urban, M. (2004). Short- and long-term reproducibility of autonomic measures in supine and standing positions. *Clinical Sci*ences, 106(1), 61-67.

Kurosawa, M., Suzuki, A., Utsugi, K. & Araki, T. (1982). Response of adrenal efferent nerve activity to non-noxious mechanical stimulation of the skin in rats. *Neuroscience Letters*, 34, 295-300.

Labyak, S. & Metzger, B. (1997). The effects of effleurage backrub on the physiological components of relaxation: a meta analysis. *Nursing Research*, 46(1), 59-62.

Lahart, S., Milmouni, F.B., Ashbel, G. & Dollberg, S. (2007). Energy expenditure in growing preterm infants receiving massage therapy. *Journal of the American College of Nutrition*, 26(4), 356-359.

Lantin, B. (2007, July 28th). Gentle strokes for happy folks. *The Times, Your Health*, p.8-9.

Latham, J. (1985). Functional anatomy and physiology of pain. *The Professional Nurse*, 42-44.

Laughlin, M.H. (1987). Skeletal muscle blood flow capacity: role of muscle pump in exercise hyperemia. *American Journal of Physiology*, 253, 993-1004.

Lee, J. & Clarkson, P.M. (2003). Plasma creatine kinase activity and glutathione after eccentric exercise. *Medicine and Science in Sports and Exercise*, 35(6), 930-937.

Leivadi, S., Hernandez-Reif, M., Field, T., O'Rourke, M., D'Arienzo, S., Lewis, D., del Pino, N., Schanberg, S. & Kuhn, C. (1999). Massage therapy and relaxation effects on University dance students. *Journal of Dance Medicine and Science*, 3(3), 108-112.

Li, Z., Wang, C., Mark, A.F.T. & Chow, D.H.K. (2005). Effects of acupuncture on heart rate variability in normal subjects under fatigue and non-fatigue state. *European Journal of Applies Physiology*, 94(5-6), 633-640.

Liao, D., Evans, G.W., Chambles, L.E. (1996). Population based study of heart rate variability and prevalent myocardial infraction. The atherosclerosis risk in communities study. *Journal of Electrocardiology*, 29(3), 189-198.

Lohman, E.B., Petrofsky, J.S., Maloney-Hinds, C., Betts-Schwab, H. & Thorpe, D. (2007). The effect of whole body vibration on lower extremity skin blood flow in normal subjects. *Medical Science Monitor*, 13(2), 71-77.

Loimaala, A., Sievanen, H., Laukkanen, R., Parkka, J., Vuori, I., & HuiKuri, H. (1999). Accuracy of a novel real-time microprocessor QRS detector for heart rate variability assessment. *Clinical Physiology*, 19(1), 84-88.

Longworth, J.C.D. (1982). Psychophysiological effects of slow stroke back massage in normotensive females. *Advances in Nursing Science*, 4(4), 44-61.

Lord, S.W., Senior, R.R., Das, M., Whittam, A.M., Murray, A. & McComb, J.M. (2001). Low-frequency heart rate variability: reproducibility in cardiac transplant recipients and normal subjects. *Clinical Science*, 100(1), 43-47.

Lundenberg, T. (1984). Long-term results of vibratory stimulation as a pain relieving measure for chronic pain. *Pain*, 20(1), 13-23.

Lundenberg, T., Nordemar, R., and Ottoson, D. (1984). Pain alleviation by vibratory stimulation. *Pain*, 20(1), 25-44.

Mackewan, S., Eungpinichpong, W., Panyumethukal, R., Chatchawan, U., Hunsawong, T. & Arayawichanon, P. (2007). Efects of traditional Thai massage versus joint mobilization on substance P and pain perception in patients with non-specific low back pain. *Journal of Bodywork and Movement Therapies*, 11, 9-16.

Madsen, O., & Lohberg, M. (1987). The low-down on lactates. *Swimming Technique*, 24(1), 21-27.

Malliani, A., Pagani, M., Lombardi, F., Furlan, R., Guzzetti, S. & Cerutti, S. (1991). Spectral analysis to assess increased sympathetic tone in arterial hypertension. *Hypertension*, 17(4), 36-42.

Marieb, E.N. (2006). *Essentials Human Anatomy and Physiology*. (8th ed.). San Francisco: Pearson/Benjamin Cummings.

Martin, N.A., Zoeller, R.F., Robertson, R.J. & Lephart, S.M. (1998). The comparative effects of sports massage, active recovery, and rest in promoting blood lactate clearance after supramaximal leg exercise. *Journal of Athletic Training*, 33(1), 30-35.

McArdle, W.D., Katch, F.I. & Katch, V.L. (2007). *Exercise physiology : energy, nutrition, and human performance*. London: Lippincott Williams & Wilkins.

McCaffrey, R. & Taylor, N. (2005). Effective anxiety treatment prior to diagnostic cardiac cathertization. *Holistic Nursing Practice*, 19(2), 70-73.

McDonagh, D., Wilson, L., Haslam, C. & Weightman, D. (2005). Good vibrations: Do electrical therapeutic massagers work? *Ergonomics*, 48(6), 680-691.

McKechnie, A.A., Wilson, F., Watson, N., & Scott, D. (1983). Anxiety states: A preliminary report on the value of connective tissue massage. *Journal of Psychosomatic Research*, 27(2), 125

McNamara, M.E., Burnham, D.C., Smith, C. & Carroll, D.L. (2003). The effects of back massage before diagnostic cardiac cathertization. *Alternative Therapies in Health and Medicine*, 9(1), 50-7.

McNaughton, L.R., Sherman, R., Roberts, S. & Bentley, D.J. (2005). Portable gas analyser Cosmed K4b2 compared to a laboratory based mass spectrometer system. *Journal of Sports Medicine and Physical Fitness*, 45(3), 315-323.a

McNeely, M.L., Magee, D.J., Lees, A.W., Bagnall, K.M., Haykowsky, M. & Hanson, J. (2004). The addition of manual lymph drainage to compression therapy cancer related lymphedema: a randomized controlled trial. *Breast Cancer Research and Treatment*, 86(2), 95–106.

McRee, L.D., Noble, S. & Pasvogel, A. (2003). Using massage and music therapy to improve postoperative outcomes. *Association of PeriOperative Registered Nurses Journal*, 78(3), 433-42.

Meeusen, R., Duclos, M., Gleeson, M., Rietjens, G., Steinacker, J. & Urhausen, A. (2006). Prevention, diagnosis and treatment of the Overtraining Syndrome. *European Journal of Sport Science*, 6(1), 1-14.

Melzack, R. & Wall, P.D. (1965) Pain mechanisms: a new theory. *Science*, 150(3699), 971-979.

Melzack, R. (1999). From gate to neuromatrix. *Pain*, Supp 6, S121-127.

Mennell, J.B. (1945). *Physical Treatments* (3rd ed.). Philadelphia: Blakiston.

Micklewright, D.P., Beneke, R., Gladwell, V. & Sellens, M.H. (2003). Blood lactate removal using combined massage and active recovery. *Medicine and Science in Sports and Exercise*, 35(5), S317.

MINTEL (2001). Health and Beauty Treatments (July). *Mintel Marketing Intelligence Report*. London: Mintel International Group Limited.

MINTEL (2007). Electronic Beauty Aids (May). *Mintel Marketing Intellegence Report*. London: Mintel International Group Limited.

Mobily, P.R., Herr, K.A. & Nicholson, A.C. (1994). Validation of cutaneous stimulation interventions for pain management. *International Journal of Nursing Studies*, 31(6), 533-544.

Moffet, H.H. (2006). How might acupuncture work? A systematic review of physiologic rationales from clinical trials. *BMC Complementary and Alternative Medicine*, 6(25), 1-8.

Monedero, B. & Donne, B. (2000). Effect of recovery interventions on lactate removal and subsequent performance. *International Journal of Sports Medicine*, 21(8), 593-597.

Moraska, A. (2005). Sports massage. A comprehensive review. *Journal of Sports Medicine and Physical Fitness*, 45(3), 370-80.

Morelli, M., Chapman, C.E. & Sullivan, S.J. (1991). Do cutaneous receptors contribute to the changes in the amplitude on the H-reflex during massage? *Electromyography and Clinical Neurophysiology*, 39(7), 441-447.

Morhenn, V.B. (2000). Firm stroking of human skin leads to vasodilatation possibly due to the release of substance P. *Journal of Dermatological Science*, 22(2), 138-144

Mori, H., Ohsawa, H., Tanaka, T.H., Taniwaki, E., Leisman, G. & Nishijo, K. (2004). Effect of massage on blood flow and muscle fatigue following isometric lumbar exercise.

Medicine Science Monitoring, 10(5), 173-178.

Moyer, C.A., Rounds, J. & Hannum, J.W. (2004). A meta-analysis of massage therapy research. *Psychological Bulletin*, 130(1), 3-18.

Myklebust, M. & Iler, J. (2007). Policy for therapeutic massage in an academic health center: a model for standard policy development. *The Journal of Alternative and Complementary Medicine*, 13(4), 471-475.

Newham, D.J., Jones, D.A. & Clarkson, P.M. (1987). Repeated high force eccentric exercise: effects on muscle pain and damage. *Journal of Applied Physiology*, 63(4), 1381-1387.

Nicholls, D.A. & Cheek, J. (2006). Physiotherapy and the shadow of prostitution: The Society of Trained Masseuses and the massage scandals of 1894. *Social Scinece and Medicine*, 62(9), 2336-2348.

Nichols, M.L., Allen, B.J., Rogers, S.D., Ghilardi, J.R., Honore, P., Luger, N.M., Finke, M.P., Li, J., Lappi, D.A., Simone, D.A. & Mantyh, P.W. (1999). Transmission of chronic nociception by spinal neurons expressing the substance P receptor. *Science*, 286, 1558-1561.

Norris, C.M. (1998). *Sports Injuries - Diagnosis and Management* (2nd Ed.). Oxford: Butterworth Heinemann.

Nosaka, K. & Clarkson, P.M. (1996a). Changes in indicators of inflammation after eccentric exercise of the elbow flexors. *Medicine and Science in Sports and Exercise*, 28(8), 953-961.

Nosaka, K. & Clarkson, P.M. (1996b). Variability in serum creatine kinase response after eccentric of the elbow flexors. *International Journal of Sports Medicine*, 17(2), 120-127.

Nosaka, K., Newton, M. & Sacco, P. (2002). Delayed onset muscle soreness does not reflect the magnitude of eccentric exercise induced muscle damage. *Scandinavian Journal of Medicine and Science in Sports*, 12(6), 337-347.

Ogai, R., Yamane, M., Matsumoto, T. & Kosaka, M. (2008). Effects of petrissage massage on fatigue and exercise performance following intensive cycle pedalling. *British Journal of Sports Medicine*, 42(4),

Okvat, H.A., Oz, M.C., Ting, W. & Namerow, P.B. (2002). Massage therapy for patients undergoing cardiac catheterization. *Alternative Therapies in Health and Medicine*, 8(3), 68-75.

Oliveri, D.J., Lynn, K. & Hong, C-Z. (1989). Increased skin temperature after vibratory stimulation. *American Journal of Physical Medicine and Rehabilitation*, 68(2), 81-85.

Ottoson, D., Ekblom, A. & Hansson, P. (1981). Vibratory stimulation for the relief of pain of dental origin. *Pain*, 10(1), 37-45.

Ouchi, Y., Kanno, T., Okada, H., Yoshikawa, E., Shinke, T., Nagasawa, S., Minoda, K., Doi, H. (2006). Changes in derebral blood flow under the prone condition with or without massage. *Neuroscience Letters*, 407, 131-135.

Pathare, N., Walter, G.A., Stevens, J.E., Yang, A., Okerke, E., Gibbs, J.D., Esterhai, J.L., Scarborough, M.T., Gibbs, C.P., Sweeney, H.L. & Vandenborne, K. (2004). Changes in inorganic phosphate and force production in human skeletal muscle after cast immobilization. *Journal of Applied Physiology*, 98, 307-314.

Patwardhan, A.R., Vallurupalli, S., Evans, J.M., Bruce, E.N. & Knapp, C.F. (1995). Override of spontaneous respiratory pattern generator reduces cardiovascular parasympathetic influence. *Journal of Applied Physiology*, 79(3), 1048-54.

Piepoli, M., Coats, A.J.S., Adamapoulos, S., Bernardi, L., Feng, Y.H., Conway, J. & Sleight,

P. (1993). Persistent peripheral vasodilatation and sympathetic activity in hypotension after maximal exercise. *Journal of Applied Physiology*, 75(4), 1807-1814.

Pocklington, A.J. & Repovich, W.E.S. (2002). The effects of massage on metabolism. *Medicine and Science in Sports and Exercise*, 34(5) S72.

Pomeranz, B., Macaulay, R.J., Caudill, M.A., Kutz, I., Adam, D., Gordon, D., Kilborn, K.M., Barger, A.C., Shannon, D.C., Cohen, R.J. & Benson, H. (1985). Assessment of autonomic function in humans by heart rate spectral analysis. *American Journal of Physiology*, 248(17), H151-153.

Porges S. W. & Byrne E.A. (1992). Research methods for measurement of heart rate and respiration. *Biological Psychology*. 34(2-3): 93-130.

Premkumar, K (2003). *The Massage Connection: Anatomy and Physiology*(2nd ed.). Philadelphia: Lippincott Williams & Wilkins.

Prober, D.M., Braun, B. & Freedson, P.S. (2004). Effects of a single bout of exercise on resting heart rate variability. *Medicine and Science in Sports and Exercise*, 36(7), 1140-1148.

Proske, U & Morgan, D.L. Muscle damage for eccentric exercise: mechanism mechanical signs, adaptation and clinical applications. *Journal of Physiology*, 537(2), 333-345.

Rahmani-Nia, F., Rahnama, N. & Ebrahim, K. (2004). Effects of warm-up on delayed onset muscle soreness. *Cellular & Molecular Biology Letters*, 9, 109-112.

Rejeski, W.J., Best, D., Griffith, P., & Kennedy, E. (1987). Sex-role orientation and the responses of men to exercise stress. *Research Quarterly*, 58, 260-264.

Rexilius, S.J., Mundt, C,. Erickson Megel, M. & Agrawal, S. (2002). Therapeutic effects of massage therapy and handling touch on caregivers of patients undergoing autologous hematopoietic stem cell transplant. *Oncology Nursing Forum*, 29(3), E35-44.

Rimoldi, O., Pagani, M., Pagani, M.R., Baselli, G. & Malliani, A. (1990). Sympathetic activation during treadmill exercise in the conscious dog: assessment with spectral analysis of heart period and systolic pressure variabilities. *Journal of the Autonomic Nervous System*, 30, S129-S132.

Rinder, A.N. & Sutherland, C.J. (1995). An investigation of the effects of massage on quadriceps performance after exercise fatigue. *Complementary Therapies in Nursing & Midwifery*, 1(4), 99-102.

Rittweger, J., Beller, G. & Felsenberg, D. (2000). Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clinical Physiology*, 20(2), 134-142.

Rittweger, J., Ehrig, J., Just, K., Mutschelknauss, M., Kirsch, K.A. & Felsenberg, D. (2002). Oxygen uptake in whole-body vibration exercise: influence of vibration frequency, amplitude, and external load. *International Journal of Sports Medicine*, 23(6), 428-432.

Rittweger, J., Schiessel, H. & Felsenberg, D. (2001). Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. *European Journal of Applied Physiology*, 86(2), 169-173.

Robertson, A., Watt, J.M. & Galloway, S.D.R. (2004). Effects of leg massage on recovery from high intensity cycling exercise. *British Journal of Sports Medicine*, 38(2), 173-177.

Rodenburg, J.B., Steenbeek, D., Schiereck, P., & Bär, P.R. (1994). Warm-up, stretching and massage diminish harmful effects of eccentric exercise. *International Journal of Sports Medicine*, 15(7), 414-419.

Roll, J.P., Vedel, J.P. & Ribot, E. (1989). Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. *Experimental Brain Research*, 76,

213-222.

Ronglan, L.T., Raastad, T. & Børgesen, A. (2006). Neuromuscular fatigue and recovery in elite female handball players. *Scandinavian Journal of Medicine & Science in Sports*, 16(4) 267-273.

Roth, D.A & Brooks, G.A. (1990). Lactate and pyruvate transport is dominated by pH gradient-sensitive carrier in rate skeletal muscle sarcolemmal vesicles. *Biochemistry & Biophysics*, 279, 386-394.

Rowell, L.B. (1988). Muscle blood flow in humans: how high can it go? *Medicine and Science in Sports and Exercise*, 20(5), 97-103.

Rowett, H.G.Q. (1988). *Basic Anatomy and Physiology* (4th ed.). London: John Murray.

Saltin, B., Rädegran, G., Koskolou, M.D. & Roach, R. (1998). Skeletal muscle blood flow in humans and its regulation during exercise. *Acta Physiologica Scandinavica*, 162(3), 421-437.

Sandercock, G.R.H., Bromley, P.D. & Brodie, D.A. (2005). The reliability of short-term measurements of heart rate variability. *International Journal of Cardiology*, 103(3), 238-247.

Saxton, J.M., Donnelly, A.E., Roper, H.P. (1994). Indices of free-radical-mediated damage following maximum voluntary eccentric and concentrate muscular work. *European Journal of Applied Physiology*, 68(3), 189-193.

Scafidi, F., Field, T. & Schanberg, S.M. (1993). Factors that predict which preterm infants benefit most from massage therapy. *Journal of Developmental and Behavioural Pediatrics*, 14(3), 1761-80.

Scafidi, F., Field, T., Schanberg, S.M., Bauer, C., Tucci, K. & Roberts, J. (1990). Massage stimulates growth in preterm infants: a replication. *Infant Behavioural Development*, 13(2), 167-188.

Schmitt, M., Blackman, D.J., Middleton, G.W., Cockcroft, J.R. & Frenneaux, M.P. (2002). Assessment of venous capacitance. Radionuclide plethysmography: methodology and research applications. *British Journal of Clinical Pharmacology*, 54(6), 565-577.

Sherer, C.L., Clelland, J.A., O'Sullivan, P., Doleys, D.M. & Canan B. (1986). The effect of high frequency vibration on cutaneous pain threshold. *Pain*, 25(1), 133-138.

Sherman, K.J., Dixon, M.W., Thompson, D. & Cherkin, D.C. (2006). Development of a taxonomy to describe massage treatments for musculoskeletal pain. *BMC Complementary and Aletrnative Medicine*, 6(24), 1-7.

Shoemaker, J.K., Tiidus, P.M., & Mader, R. (1997). Failure of manual massage to alter limb blood flow: Measures by Doppler ultrasound. *Medicine and Science in Sports and Exercise*, 29(5), 610-614.

Siinereich, R., Kark, J.D., Friedlander, Y., Sapoznikov, D. & Luria, M.H. (1998). Five minute recordings of heart rate variability for population studies: repeatability and age-sex characteristics. *Heart*, 80, 156-162.

Sloan, R.P., Shapiro, P.A., Bagiella, E., Boni, S.M., Paik, M., Bigger, J.T., Steinman, R.C. & Gorman, J.M. (1994). Effect of mental stress throughout the day on cardiac autonomic control. *Biological Psychology*, 37(2), 89-99.

Smith, K.C., Comite, S.L., Balasubramanian, S., Carver, A. & Liu, J.F. (2004). Vibration anesthesia: A noninvasive method of reducing discomfort prior to dermatologic procedures. *Dermatology Online Journal*, 10(2).

Smith, L.L., Keating, M.N., Holbert, D., Spratt, D.J., McCammon, M.R., Smith, S.S. & Israel, R.G. (1994). The effects of athletic massage on delayed onset muscle soreness, creatine kinase, and nutrophil count: A preliminary report. *The Journal of Orthopaedic Sports and Physical Therapy*, 19(2), 93-99.

Sofaer, B. (1999). *Pain*. Stanley Thornes: Cheltenham.

Sparrow, K. (2007). Analysis of heart rate variability in acupuncture practice: Can it improve outcomes? *Medical Acupuncture*, 19(1), 37-41.

Stainsby, W.N. (1986). Biochemical and physiological bases for lactate production. *Medicine and Science in Sports and Exercise*, 18(3), 341-343.

Stamford, B.A. (1985). Massage for athletes. *The Physician and Sportsmedicine*, 13(10), 178.

Stark, R., Schienle, A., Walter, B. & Vaitl, D. (2000). Effects of paced respiration on heart period and heart period variability. *Psychophysiology*, 37(3), 302-309.

Stegall, H.F., Martin, W.E. & Rushmer, R.F. (1966). A simple method for cuff inflation in plethysmography. *Journal of Applied Physiology*, 21(2), 700.

Stewart, J.M., Karman, C., Montgomery, L.D. & McLeod, K.J. (2005). Plantar vibration improves leg fluid flow in perimenopausal women. *American Journal of Physiology*, 288(3), 623-629.

Stringer, J., Swindell, R. & Dennis, M. (2008). Massage in patients undergoing intensive chemotherapy reduces serum cortisol and prolactin. *Psycho-Oncology*, 17(10), 1024-31.

Sullivan, Wiliams, Seaborne, Morelli, M. (1991). Effects of massage on alpha motorneuron excitability. *Physical Therapy*, 71(8), 555-560.

Tan, J.C., Roux, E.B., Dunand, J., and Vischer, T.L. (1992). Role of physical therapy in the management of common low back pain. *Bailliere's Clinical Rheumatology*, 6(3), 629-655.

Tarkiainen, T.H., Timonen, K.L., Tiittanen, P., Hartikainen, J.E.K., Pekkanen, J., Hoek, G., Ibald-Mulli, A. & Vanninen, E.J. (2005). Stability over time of short-term heart rate variability. *Clinical Autonomic Research*, 15(6), 394-399.

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996). Heart Rate Variability: Standards of measurement, physiological interpretation and clinical use. *Circulation*, 93(5), 1043-1065.

Task Force on Syncope, European Society of Cardiology (2004). Guidelines on Management (Diagnosis and Treatment) of Syncope. *European Heart Journal*, 25, 2054-2072.

Tatum, W.O., Husain, A., Benbadis, S. & Kaplan, P.W. (2007). Handbook of EEG Interpretation. New York: Demos Medical Publishing.

Taylor, A.G., Galper, D.I., Taylor, P., Rice, L.W., Andersen, W., Irvin, W., Wang, X.Q. & Harrell, F.E. (2003). Effects of adjunctive Swedish massage and vibration therapy on short-term postoperative outcomes: a randomized, controlled trial. *The Journal of Alternative and Complementary Medicine*, 9(1), 77-89.

Tegtbur, U., Busse, M.W., & Braumann, K.M. (1993). Estimation of an individual equilibrium between lactate production and catabolism during exercise. *Medicine and Science in Sports and Exercise*, 25(5), 620-627.

Tiidus, P.M. (1997). Manual massage and recovery of muscle function following exercise: A literature review. *The Journal of Orthopaedic Sports and Physical Therapy*, 25(2), 107-112.

Tiidus, P.M., & Ianuzzo, C.D. (1983). Effects of intensity and duration of muscular exercise on delayed soreness and serum enzyme activities. *Medicine and Science in Sports and*

Exercise, 15(6), 461-465.

Tiidus, P.M., & Shoemaker, J.K. (1995). Effleurage massage, muscle blood flow and long-term post-exercise strength recovery. *International Journal of Sports Medicine*, 16(7), 478-483.

Tortora, G.J. (2005). *Principles of Human Anatomy* (10^{th} ed.). New Jersey : John Wiley & Sons.

Tschakovsky, M.E., Shoemaker, J.K. & Hughson, R.L. (1995). Beat-by-beat forearm blood flow with Doppler ultrasound and strain-gauge plethysmography. *Journal of Applied Physiology*, 79(3), 713-719.

Tsuji, H., Ferdinand, J.V., Manders, E.S., Evans, J.C., Larson, M.G., Feldman, C.L. & Levy, D. (1996). Determinants of heart rate variability. *Journal of Clinical Cardiology*, 28(6), 1539-1547.

Valic, Z., Buckwalter, J.B. & Clifford, P.S. (2005). Muscle blood flow response to contraction: influence of venous pressure. *Journal of Applied Physiology*, 98(1), 72-77.

Vanhuyse, V.J. & Raman, E.R. (1971). Interpretation of pressure changes in plethysmography. *Physics in Medicine and Biology*, 16(1), 11-117.

vanRavenswaaij-Arts, C.M.A., Kollee, L.A.A., Hopman, J.C.W., Stoelinga, G.B.A. & Van Geijn, H.P. (1993). Heart Rate Variability. *Annals of Internal Medicine*, 118(6), 436-447.

Vezzoli, A., Gussoni, M., Greco., F & Zetta, L. (2003). Effects of temperature and extracellular pH on metabolites: kinetics of anaerobic metabolism in resting muscle by ^{31}P- and ^{1}H-NMR spectroscopy. *The Journal of Experimental Biology*, 206, 3043-3052.

Vincent, S., Berthon, P., Zouhal, H., Moussa, E., Catheline, M., Bentué-Ferrer, D. & Gratas-Delamarche A. (2004). Plasma glucose, insulin and catecholamine responses to a Wingate test in physically active women and men. *European Journal of Applied Physiology*, 91,15-21.

Voet, D. & Voet, J.G. (1995). *Biochemistry*. New York: John Wiley & Sons Inc.

von Duvillard, S.P. (2001). Exercise lactate levels: simulation and reality of aerobic and anaerobic metabolism. *Eurpean Journal of Applied Physiology*, 86, 3-5.

Wakim, K.G., Martin, G.M., Terrier, J.C., Elkins, E.C., & Krusen, F.H. (1949). The effects of massage on the circulation in normal and paralysed extremities. *Archives of Physical Medicine*, 30, 135-144.

Wang, H.L. & Keck, J.F. (2004). Foot and hand massage as an intervention for postoperative pain. *Pain Management Nursing*, 5(2), 59-65.

Ward, S.A. (2004). Physiology of breath I. *Surgery*, 22(8), i-v.

Warren, G.L., Lowe, D.A. & Armstrong, R.B. (1999). Measurement tools used in the study of eccentric contraction-induced injury. *Sports Medicine*, 27(1), 43-59.

Watt, J. (1999). *Massage for Sport*. Ramsbuty: The Crowood Press Ltd.

Weber, M.D., Servedio, F.J., & Woodall, W.R. (1994). The effects of three modalities on delayed onset muscle soreness. *The Journal of Orthopaedic Sports and Physical Therapy*, 20(5), 236-242.

Weerapong, P., Hume, P.A. & Koly, G.S. (2005). The mechanism of massage and effects on performance, muscle recovery and injury prevention. *Sports Medicine*, 35(3), 235-257.

Weinstein, J. (1986). Mechanisms of spinal pain, the dorsal root ganglion and its role as a mediator of low back pain. *Spine*, 11, 999-1001.

Weinstein, J., Pope, M., Schmidt, Seroussi, R. (1988). Neuropharmacologic effects of vibration on the dorsal root ganglion. *Spine*, 13(5), 521-525.

Weinstein, Y., Bediz, C., Dotan, R. & Falk. B. (1998). Reliability of peak-lactate, heart rate, and plasma volume following the Wingate test. *Medicine and Science in Sports and Exercise*, 30(9), 1456-60.

Weltman, A., Stamford, B.A., & Fulco, C. (1979). Recovery from maximal effort exercise: Lactate disappearance and subsequent performance. *Journal of Applied Physiology.: Respiratory, Environmental and Exercise Physiology*, 47(4), 677-682.

Wendler, M.C. (2003). Effects of Tellington Touch in healthy adults awaiting venipuncture. *Research in Nursing and Health*, 26(1), 40-52.

Westerblad, H., Allen, D.G. & Lännergren, J. (2002). Muscle fatigue: lactic acid or inorganic phosphate the major cause. *News in Physiological Sciences*, 17, 17-21.

Wikström, S., Gunnarsson, T. & Nordin, C. (2003). Tactile stimulus and neurohormonal response: a pilot study. *International Journal of Neuroscience*, 113, 787-793.

Wilkinson, I.B. & Webb, D.J. (2001). Venous occlusion plethysmography in cardiovascular research: methodology and clinical applications. *British Journal of Clinical Pharmacology*, 52(6), 631-647.

Wilkinson, S., Aldridge, J., Salmon, I., Cain, E. & Wilson, B. (1999). An evaluation of aromatherapy massage in palliative care. *Palliative Medicine*, 13(5), 409-417.

Winsley, R.J., Armstrong, N., Bywater, K. & Fawkner, S.G. (2003). Reliability of heart rate variability measures at rest and during light exercise in children. *British Journal of Sports Medicine*, 37(6), 550-552.

Wood, L., (2000). *Physiology of Pain*. Churchill Lingingston: London pp. 75-83.

Wyper, D.J. & McNiven, D.R. (1976). Effects of some physiotherapeutic agents on skeletal muscle blood flow. *Physiotherapy*, 62(3), 83-85.

Yang, D. & Sacco, P. (2002). Reproducibility of air plethysmography for the evaluation of arterial and venous function of the lower leg. *Clinical Physiology*, 22(6), 379-382.

Ylinen, J., & Cash, M. (1988). Sports Massage. London: Stanley Paul.

Young, S.N. (2007). How to increase serotonin in the human brain without drugs. *Journal of Psychiatry & Neuroscience*, 32(6), 394-399.

Zainuddin, Z., Newton, M., Sacco, P. & Nosaka, K. (2005). Effects of Massage on Delayed-Onset Muscle Soreness, Swelling, and Recovery of Muscle Function. *Journal of Athletic Training*, 40(3), 174-180.

Zeitlin, D., Keller, S.E., Shiflett, S.C., Schleifer, S.J & Bartlett, J.A. (2000). Immunological effects of massage therapy during academic stress. *Psychosomatic Medicine*, 62(1), 83-84.

APPENDICES

APPENDICES

APPENDIX 1

Test-retest reliability of the Polar 810*i*™ as a time and frequency domain measurement of heart rate variability

INTRODUCTION

7.1 Overview

The Polar 810*i* datalogger is a none invasive telemetric system requiring the use of a simple transmitter belt; and therefore negates the need for leads and direct wiring (Delaney, Leong & Brodie, 2000 and Akselrod *et al.*, 1985). Moreover, Polar Precision Performance analysis software (Polar, Kempele, Sweden) has been shown to be highly correlated with 24hr ECG Holter recordings in all variables of the frequency and time domain (Bigger *et al.*, 1993; Loimaala *et al.*, 1999; and Delaney, Leong & Brodie, 2001).

Although the Polar method is a validated measure of HRV, the test-retest reliability has not previously been researched. Furthermore, there is a paucity of research regarding the most relaxing body position in which to rest the subject, in order to collect the R-R data.

7.2 Study aims

The aim of the study was to:-

- investigate the test-retest reliability of the Polar 810*i* R-R data collection watch, and Polar Precision performance software to measure HRV.
- determine the most relaxing position in which to measure HRV; deemed by time and frequency domain HRV, heart rate, systolic blood pressure and rate pressure product.

MATERIALS AND METHODS

7.3 Subjects

20 healthy male subjects (mean age 23.2±4.4yrs) participated in the study. Each subject arrived at the laboratory in a 1 hour post-prandial condition, had not exercised, consumed caffeine, or alcohol for at least 24 hours prior to testing. Room temperature was controlled between 21 - 24°C. Each subject was tested a total of eight times (four postures, twice) within a fourteen day period, and tested at approximately the same time on each day to reduce the effect of diurnal variations on HRV (vanRavenswaaij-Arts *et al.*, 1993).

7.4 Adopted postures

7.4.1 *Standing posture:* Subjects were required to stand with their feet shoulder width apart, arms by the side, looking straight ahead

7.4.2 *Sitting posture:* Subjects sat on a cushioned chair, with the knee flexed at 90°, palms on thighs, and looking straight ahead

7.4.3 *Laying on a therapy couch:* Subjects lay in a supine position on a therapy couch, with the torso at 45° and the legs horizontal.

7.4.4 *Supine posture on a therapy couch:* Subjects lay in a supine position on a therapy couch.

7.5 Data collection

7.5.1 *Heart rate:* HR data were collected using the Polar 810*i*™. Subjects adopted a specified posture for 15mins to establish a resting baseline, with a further 5mins to record the heart rate data. During the 20min period, subjects were requested to refrain from talking or making any unnecessary body movements.

7.5.2 *Blood pressure:* Blood pressure was recorded on completion of the test. This was taken from the left arm using an aneroid sphygmomanometer and stethoscope.

RESULTS

7.6 Heart rate variability

Table A1.1 shows the sympathetic and parasympathetic indicators of HR control. The results show that a supine position on a therapy couch was the most relaxing, demonstrated by the lowest HR, LFnorm and LF:HF Ratio, and highest HFnorm.

Table A1.1 Heart Rate Variability (time and frequency domain) for standing, sitting, laying on a couch and supine. Parasympathetic, Sympathetic and Sympathovagal indicators (n=20).

	Standing		Sitting		Laying on couch		Supine	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
HR	74.5±7.2	75.4±7.1	62.9±4.4	63.2±4.1	57.7±5.9	57.6±7.0	53.9±5.4	53.3±5.3
LF norm	85.63±7.0	85.6±7.1	67.2±8.7	67.9±8.5	54.8±12.5	54.2±12.6	51.1±10.9	50.1±10.6
LF:HF Ratio	7.05±3.3	7.93±3.1	1.98±0.91	2.08±0.97	1.38±0.61	1.27±0.51	1.20±0.65	1.14±0.71
HF norm	14.37±7.1	14.4±7.1	33.8±8.7	33.1±8.5	45.2±12.5	45.8±12.4	48.9±10.9	49.9±10.6
RMSSD	30.1±19.6	33.7±18.1	47.2±13.2	55.6±14.1	57.2±17.8	60.1±19.4	61.2±15.6	62.8±17.3
pNN50	5.1±1.9	5.8±1.3	10.9±2.3	12.7±2.1	14.4±4.5	17.3±7.5	17.1±4.2	17.5±3.3

7.7 Blood pressure

There was no significant difference between blood pressure between Test 1 and Test 2 (Table A1.2). The results show that a supine position on a therapy couch was the most relaxing, demonstrated with the lowest systolic blood pressure.

Table A1.2 Systolic blood pressure for standing, sitting, laying on a couch and supine (n=20).

	Standing	Sitting	Laying on couch	Supine
Test 1	127.7±4.3	117.4±7.7	107.9±4.2	103.8±3.8
Test 2	127.4±5.5	117.9±3.7	107.9±4.4	103.1±4.2

7.8 Rate pressure product

There was no significant difference between rate pressure product between Test 1 and Test 2 (Table A1.3). The results show that a supine position on a therapy couch was the most relaxing, demonstrated with the lowest rate pressure product. Further analysis showed that rate pressure product correlated highly with LF:HF ratio (r^2=0.8017).

Table A1.3 Rate pressure product for standing, sitting, laying on a couch and supine (n=20).

	Standing	Sitting	Laying on couch	Supine
Test 1	9428±1032	7402±632	6103±684	5604±831
Test 2	9625±789	7269±518	6142±404	5486±953

7.9 Test-retest reliability for time and frequency domain measure of HRV

Analysis of the test-retest reliability for time and frequency domain measures of HRV, using correlation analysis and Bland-Altmans 95% Limits of Agreement, indicated that the results showed good agreement from Test 1 to Test 2 for heart rate (A1.1&A1.2), LFnorm (A1.3&A1.4), HFnorm (A1.5&A1.6) and LF:HFratio (A1.7&A1.8).

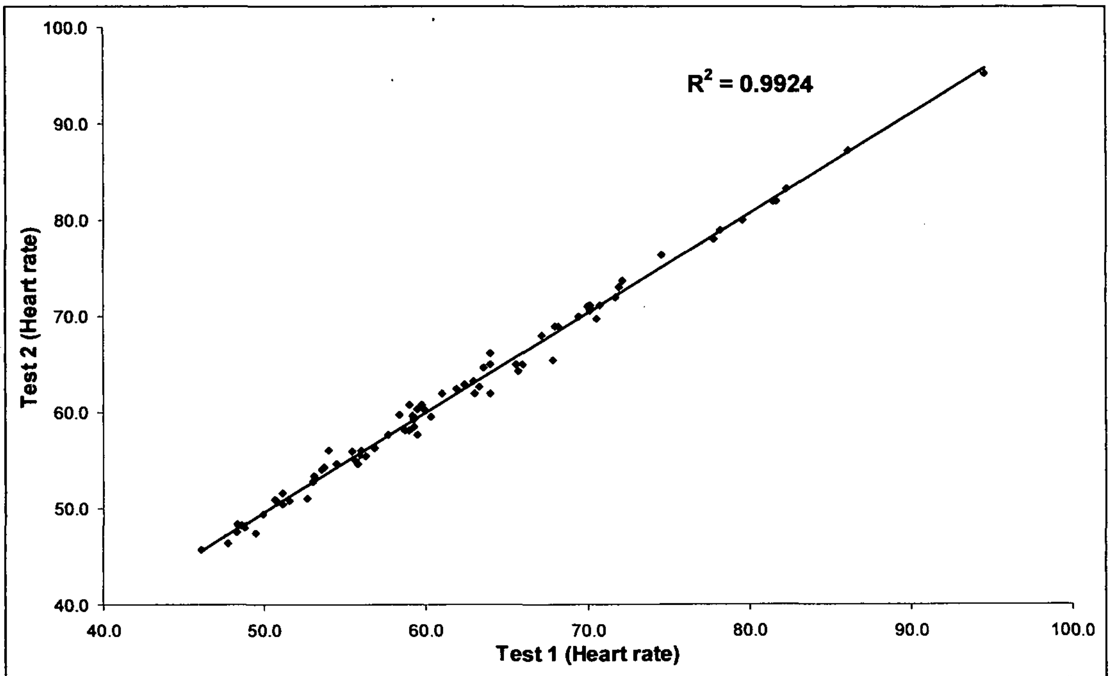


Figure A1.1 Correlation analysis for Test 1 *vs* Test 2 for heart rate (r^2=0.9924)

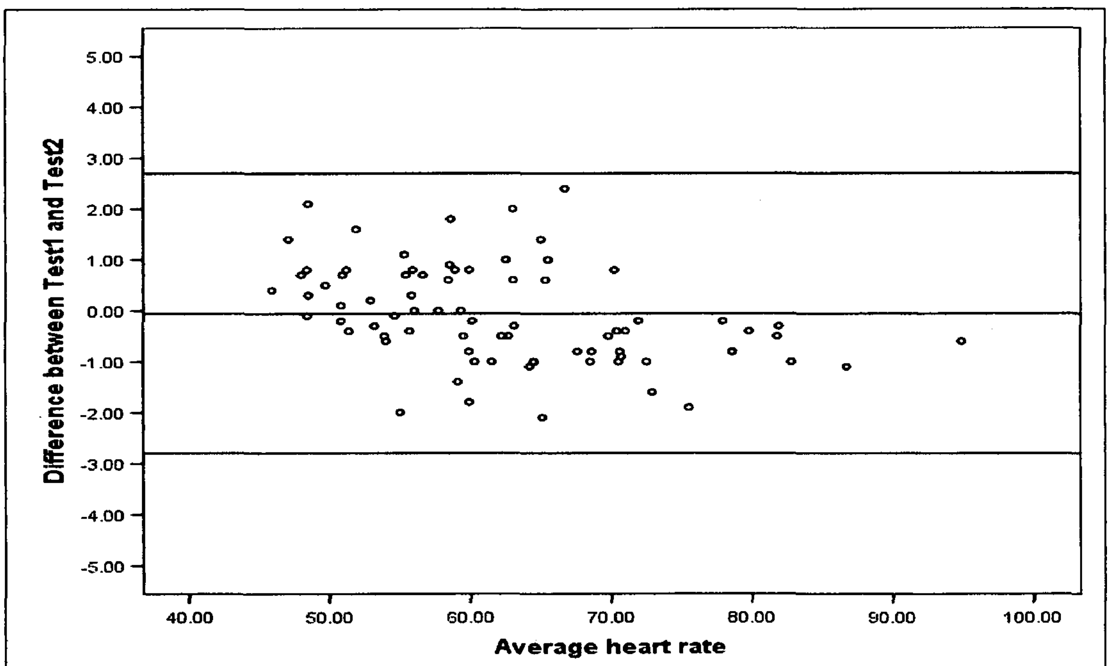


Figure A1.2 Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for heart rate

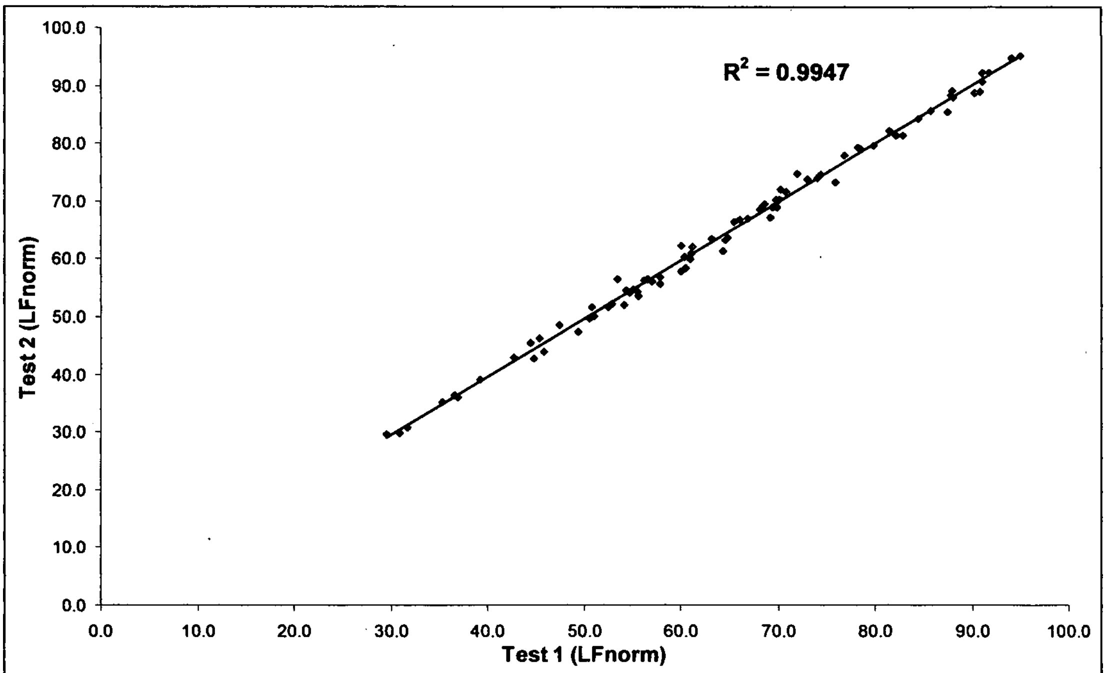


Figure A1.3 Correlation analysis for Test 1 *vs* Test 2 for LFnorm (r^2=0.9947)

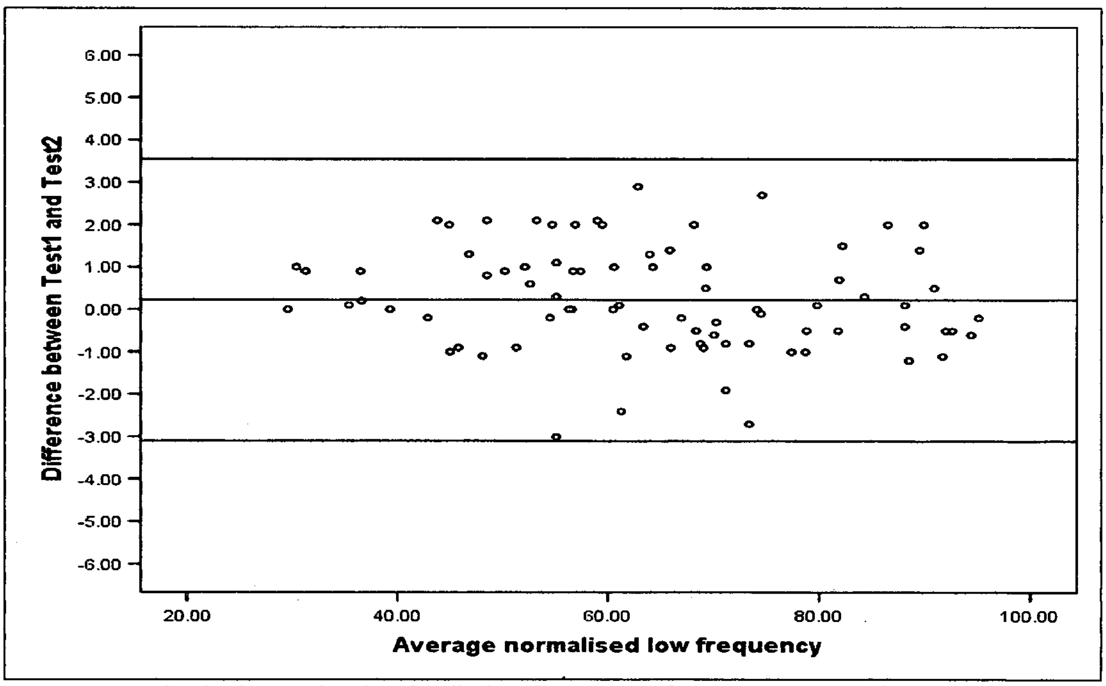


Figure A1.4 Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for LFnorm

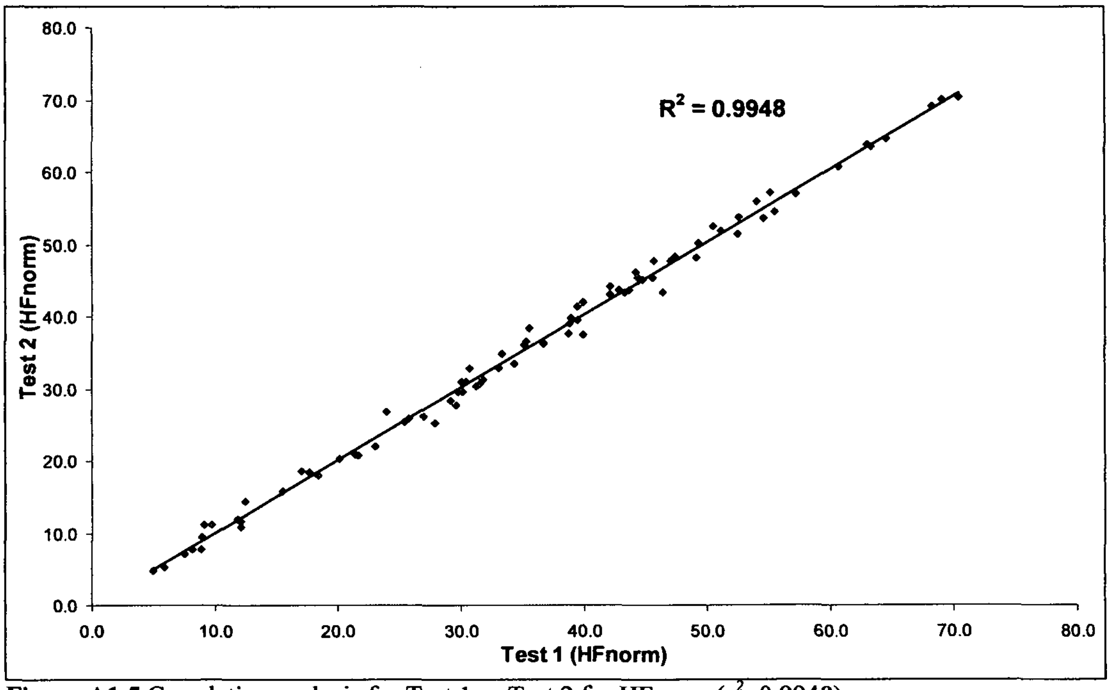


Figure A1.5 Correlation analysis for Test 1 *vs* Test 2 for HFnorm (r^2=0.9948)

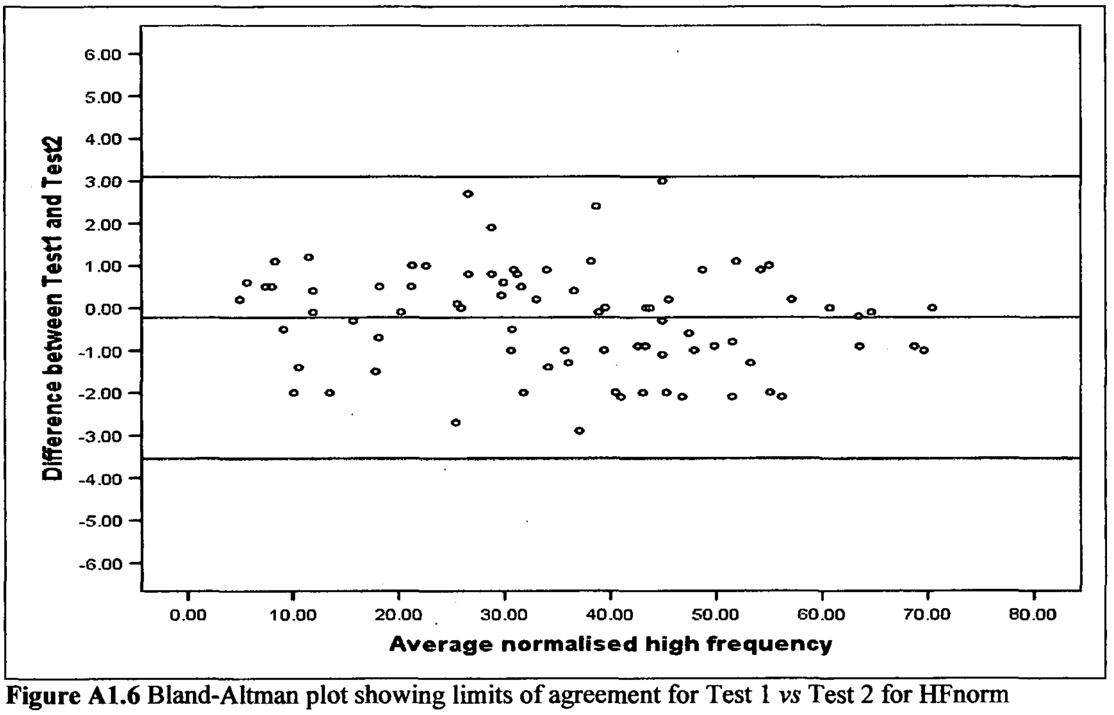


Figure A1.6 Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for HFnorm

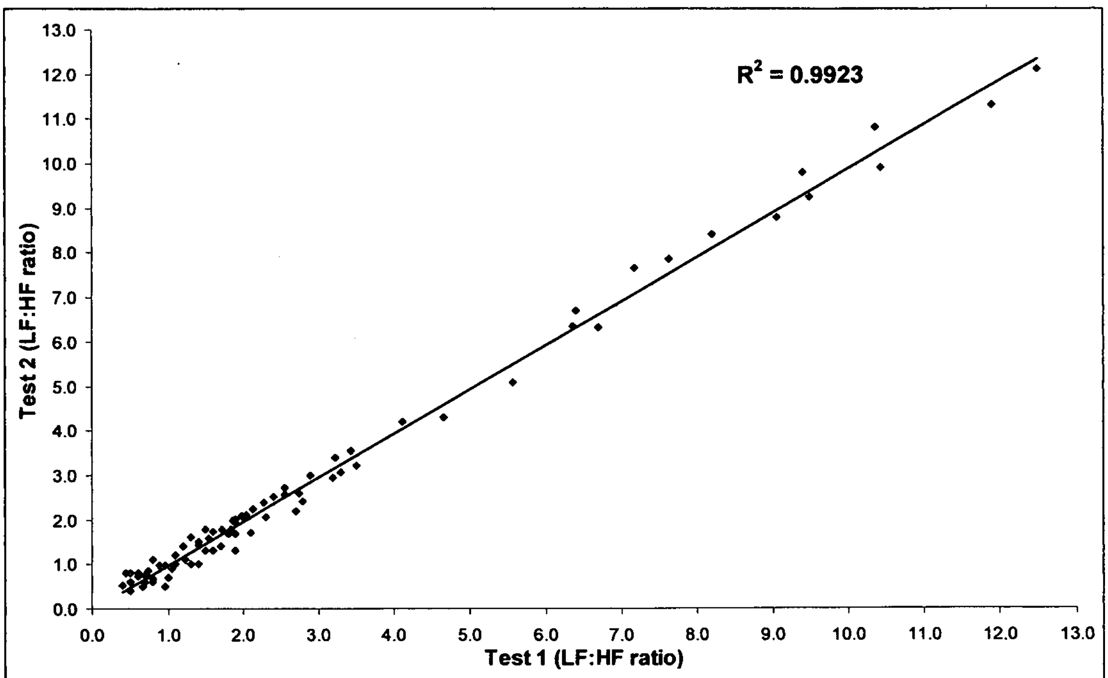


Figure A1.7 Correlation analysis for Test 1 *vs* Test 2 for LF:HFratio (r^2=0.9923)

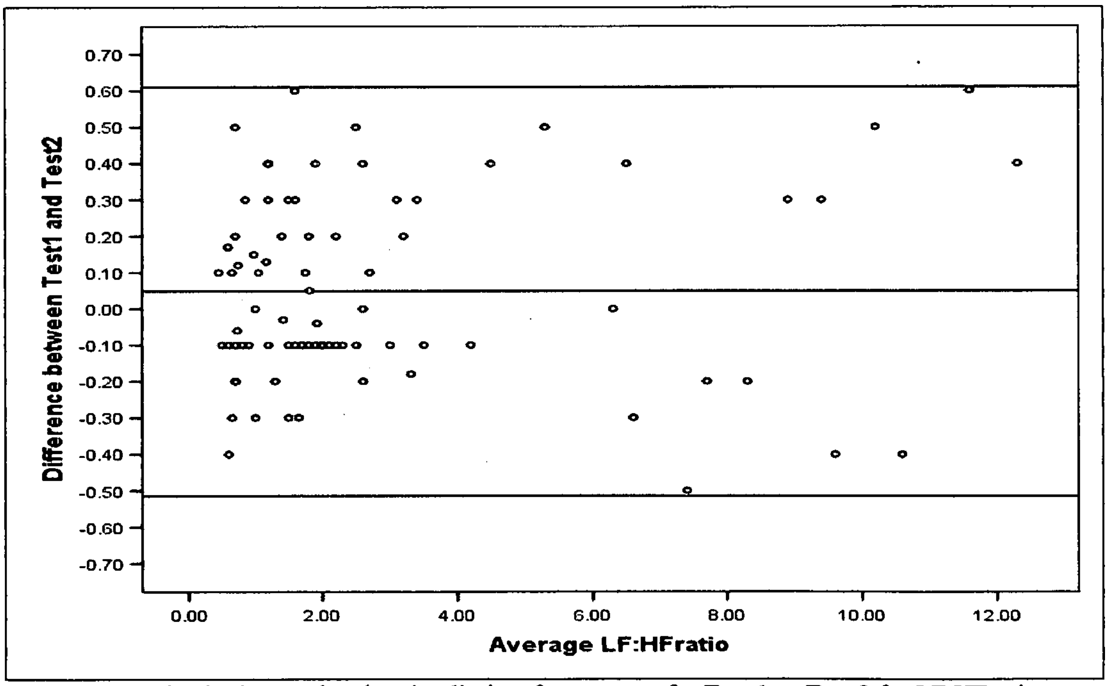


Figure A1.8 Bland-Altman plot showing limits of agreement for Test 1 *vs* Test 2 for LF:HFratio

7.10 Conclusions

When considered jointly, the results of HRV, heart rate, systolic blood pressure and rate pressure product highlighted that the supine posture promoted a greater degree of relaxation. Therefore, during data collection of HRV in Chapter 3 & 4, a supine posture was adopted. Furthermore, the 95% Limits of Agreement results confirm that the Polar 810*i* datalogger and Polar Precision Performance analysis software are a reliable measure of time and frequency domain HRV.

APPENDIX 2

The effect of a 30mins continuous manual leg massage on recovery from anaerobic exercise

INTRODUCTION

8.1 Study aims

The aim of this investigation was to verify the conclusions of our preliminary study (by Jones & Cotterrell, 1999), and extend these by including additional physiological and psychological variables to fully assess recovery. In order to do this, the investigation compared the effect of 30mins manual leg massage (MM) with Rest (R) and recumbent cycling exercise (CE) at 60%HR_{max}, on recovery from a single bout of maximal intensity exercise. The time of the massage was 30mins, identical to the preliminary study by Jones & Cotterrell (1999), and is consistent with the recommendation for the duration of leg massage, detailed in Cash (1999) Boone & Cooper (1995) and DeDomenico (2007). Body position was standardised during recovery between the three methods to minimise postural variations. This is the first research study investigating massage to do so.

MATERIALS AND METHODS

8.2 Subjects

8.2.1 The 10 subjects (mean±SD: 5 males 23.6±5.8yrs, 173.2±8.8cm and 76.6±11.4kg; and 5 females 24.8±2.6yrs, 165.4±8.9cm and 65.3±3.5kg) participating in the investigation were physically active (Table A2.1). Each subject completed the three recoveries from the WAnT in a different order (Table A2.2) to minimise bias. The recovery period was 30mins.

Table A2.1 Age, height, weight, maximum heart rate and main participation sport of the five male and five female subjects participating in Investigation 4.

Subject No.	Gender	Age	Height	Weight	Max HR	Main Sport
1	M	33	187	82.2	186	Swimming
2	F	24	162	64.5	195	Triathlon
3	F	25	153	62.1	200	Hockey
4	M	25	164	63.4	198	Running
5	M	21	167	92	193	Rugby
6	F	22	165	63.5	196	Triathlon
7	M	19	174	71.7	195	Football
8	M	20	174	68.5	191	Hockey
9	F	29	170	65.5	197	Netball
10	F	24	177	71.3	200	Basketball

Table A2.2 Randomly assigned recovery methods for each subject during Investigation 4.

Subject	1	2	3	4	5	6	7	8	9	10
MM	1	2	3	1	3	1	2	2	1	3
CE	2	3	1	3	2	2	3	1	3	2
R	3	1	2	2	1	3	1	3	2	1

8.3 Preliminary measurements

Maximal oxygen uptake and maximum heart rate was estimated a week prior to the experiment (detailed in Chapter 2). The results of the test were used to set the work rate for the recumbent cycling exercise recovery.

8.4 Warm up

Protocol detailed in Chapter 5.

8.5 Exercise Test

Wingate Anaerobic Test (WAnT): Protocol detailed in Chapter 5.

8.6 Recovery Protocols

8.6.1 Manual Leg Massage (MM): The posterior aspect of the leg was massaged in a prone position, followed by the anterior in a supine position for the same time period. The general sequence of massage is detailed in Table A2.3. Subjects were requested to remain still and quiet throughout.

Table A2.3 General sequence of the leg massage (manual and vibratory) for prone then supine positions (total time = 30mins).

Prone	Time (mins)	Supine	Time (mins)
Superficial effleurage of whole leg	1	Superficial effleurage of whole leg	1
Superficial effleurage of hamstrings	0.5	Superficial effleurage of quadriceps	0.5
Deep effleurage of hamstrings	1	Deep effleurage of quadriceps	1
Kneading of hamstrings	1	Kneading of quadriceps	1
Wringing of hamstrings	1	Wringing of quadriceps	1
Superficial effleurage of whole leg	0.5	Superficial effleurage of whole leg	0.5
Deep effleurage of calf	0.5	Deep effleurage of tibialis anterior	0.5
Kneading of the calf	0.5	Kneading of tibialis anterior	0.5
Deep effleurage of whole leg	1	Deep effleurage of whole leg	1
Superficial effleurage of whole leg	0.5	Superficial effleurage of whole leg	0.5

8.6.2 Rest (R): Subjects were required to adopt a prone position, followed by a supine position for the same time period.

8.6.3 Recumbent continuous cycling exercise (CE): Protocol detailed in Chapter 5.

8.7 Data collection

Protocols for rating of perceived exertion, blood lactate, heart rate, blood pressure, pulmonary ventilation, metabolic rate, leg skin & aural temperature and perception of feeling are detailed in Chapter 2. The values for metabolic rate and pulmonary ventilation are an average of data recorded in the previous minute; apart from immediately post WAnT where a 10sec average was taken.

8.8 Timeline of measurements

Prior to the baseline measurements, subjects rested for 5mins in a supine position in a quite room at an ambient temperature. The T_{Zero} measurement was taken immediately on completion of the WAnT, and prior to the start of the recovery mode. The 30min measurement were taken immediately on completion of the recovery mode whilst the subjects were laying in a supine position. Table A2.4 details which measurements were taken, and when.

Table A2.4 Measurements taken at each time point

	BLa	BP	HR	Metabolic rate	Pulmonary ventilation	Body temperature	PoF
Baseline	✓	✓	✓	✓	✓	✓	✓
Warm up	✓	✓	✓	✓	✓		✓
T_{Zero}	✓	✓	✓	✓	✓		✓
3mins post	✓	✓	✓	✓	✓		✓
5mins post	✓	✓	✓	✓	✓		✓
10mins post	✓	✓	✓	✓	✓		✓
20mins post	✓	✓	✓	✓	✓	✓	✓
30mins post	✓	✓	✓	✓	✓	✓	✓

8.9 Statistical Analysis:

Detailed in Chapter 5

RESULTS

8.10 30sec Wingate Anaerobic Test

The mean power output (Watts) for each of the three WAnT trials were not significantly different (p=0.882). The mean power output for the 30 tests (3 trials x 10 subjects) was 8.3±1.2W · Kg^{-1}. When corrected for the subject's weight, no significant differences were seen between the male (8.4±1.6W · Kg^{-1}) and female (8.0±1.3W · Kg^{-1}) subjects participating in the study (p=0.310). On completion of the WAnT mean rating of perceived exertion was 20 (IQR 19, 20) (Maximal Exertion).

8.11 The effect of a manual leg massage on blood lactate concentrtaion

Baseline BLa was 1.2±0.3mmol · l^{-1}. On completion of the WAnT, lactate had increased to 9.8±1.2mmol · l^{-1}. During the recovery period, highest BLa, 13.03±1.4 mmol · l^{-1}, was seen 3mins following the completion of the WAnT (Figure A2.1). The BLa concentration for MM decreased more rapidly than R. By 30mins, BLa concentration remained high at 7.2±0.6 mmol · l^{-1} for R, but had decreased to 5.9±0.9 mmol · l^{-1} for MM, which was significantly lower compared to R (p=0.002). The BLa for CE decreased more rapidly than either MM or R and was 3.1±0.5mmol · l^{-1} at the same time point, significantly lower than the other two conditions (p<0.001). To estimate the clearance time back to baseline, linear trend analysis showed that time from highest lactate at 3mins post down to the baseline was estimated to be 70±7.5mins for R, 52±6.4mins for MM and 36±2.8mins for CE (Figure A2.2).

Figure A2.3-2.5 demonstrates that for MM, R and CE the individual subjects all responded in a similar fashion to that depicted in the group mean.

The results indicate that MM had a greater effect, clearing BLa more effectively during the 30min recovery method compared to R. CE cleared BLa more rapidly than MM.

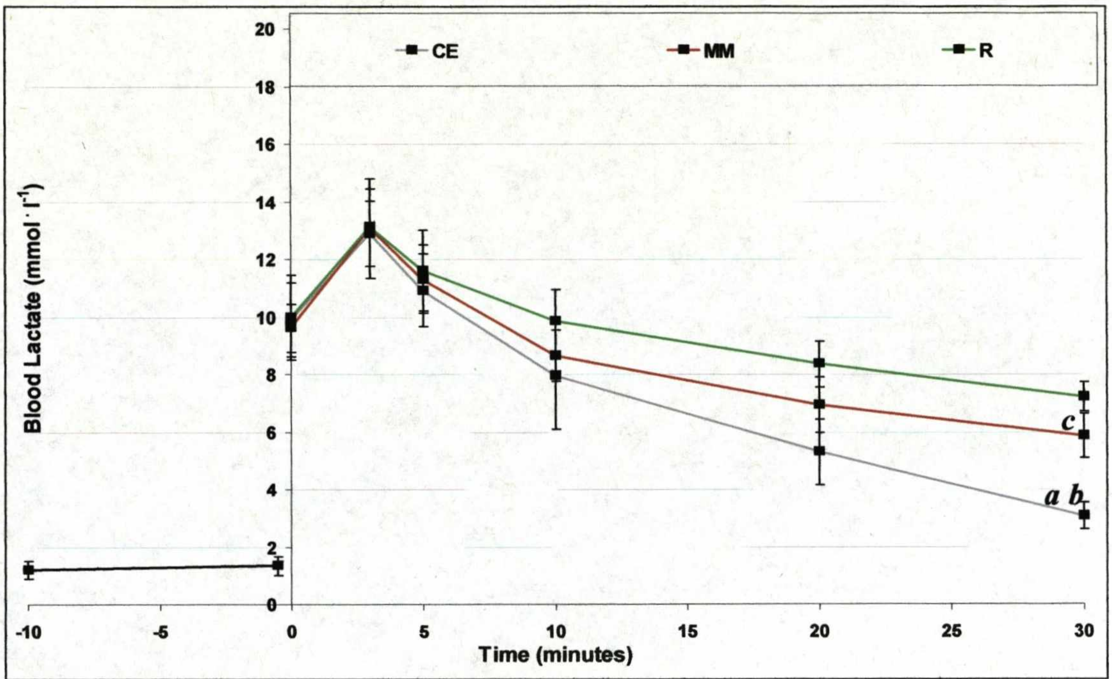


Figure A2.1 Blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM, ***b*** = CE vs R and ***c*** = MM *vs* R (*n* = 10).

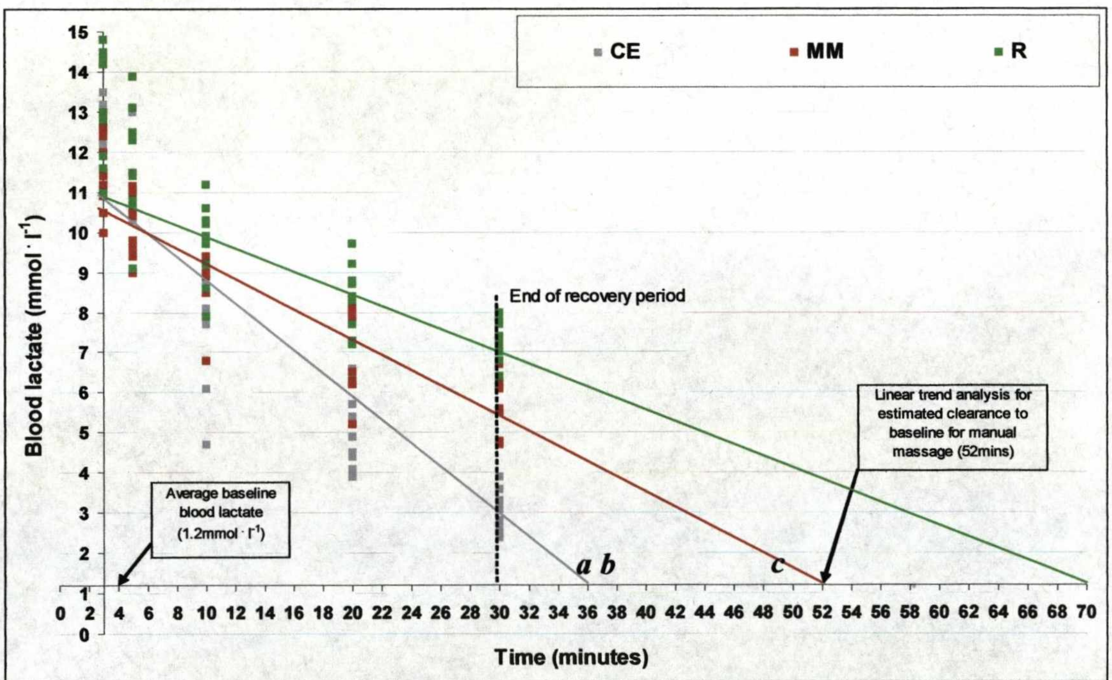


Figure A2.2 Estimated total clearance time of blood lactate (mmol · l^{-1}) to baseline following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM, ***b*** = CE *vs* R and ***c*** = MM *vs* R (*n* = 10).

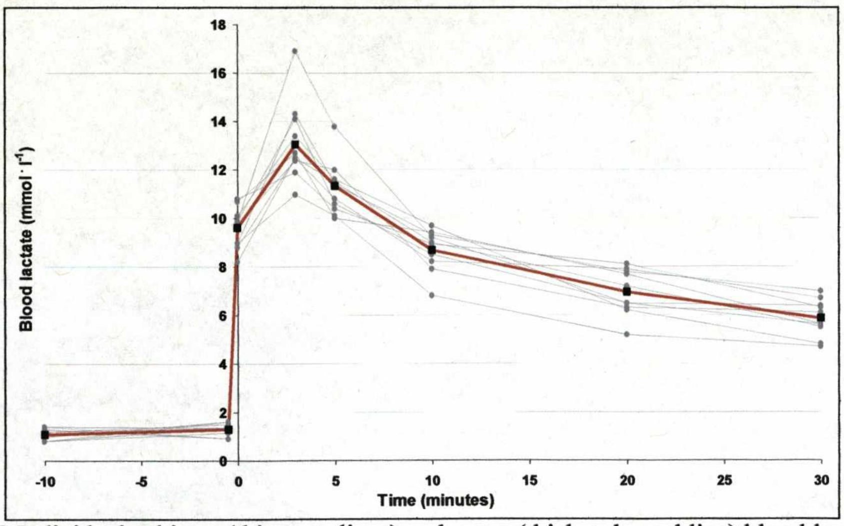


Figure A2.3 Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for manual leg massage (MM).

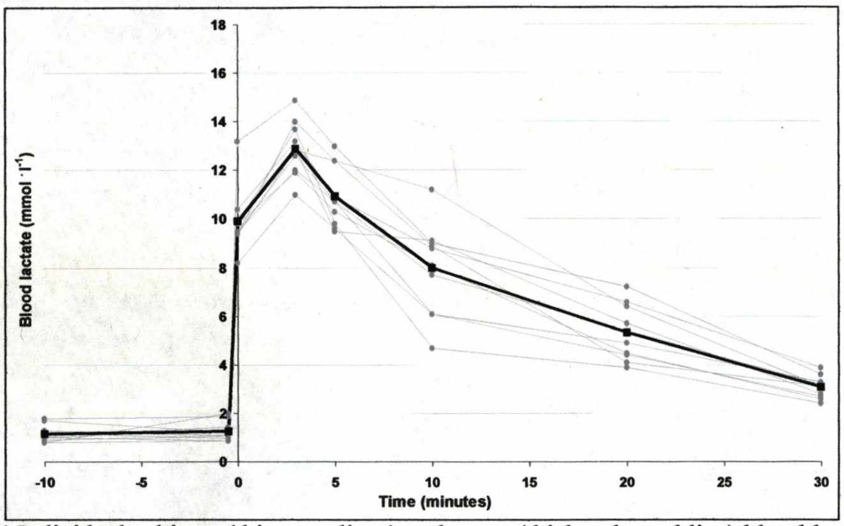


Figure A2.4 Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for continued cycling exercise (CE).

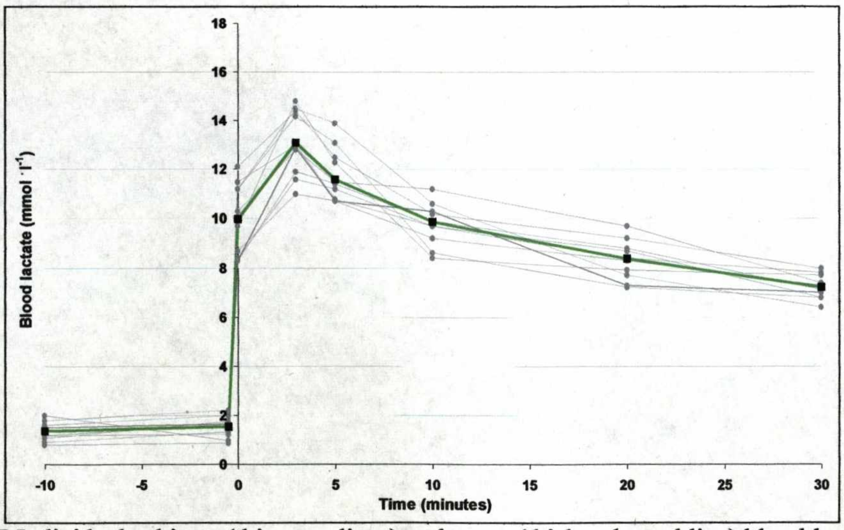


Figure A2.5 Individual subjects (thin grey lines) and mean (thick coloured line) blood lactate (mmol · l^{-1}) response following a bout of maximal intensity exercise for rest (R).

8.12 The effect of a manual leg massage on heart rate

Baseline HR was 81.4±5.2bpm. On completion of the WAnT HR increased to 174.4±7.1bpm (Figure A2.6), this was followed by a gradual decrease over time for all three recovery methods similar to that seen in systolic blood pressure. The heart rate for MM (80.0±7.1bpm) was somewhat lower than that of R (84.9±8.8bpm); however both were significantly lower (p<0.001) than CE (117.2±2.4bpm). Predictably, the HR for CE remained elevated at ~60%HR_{max} (117.2±2.4bpm).

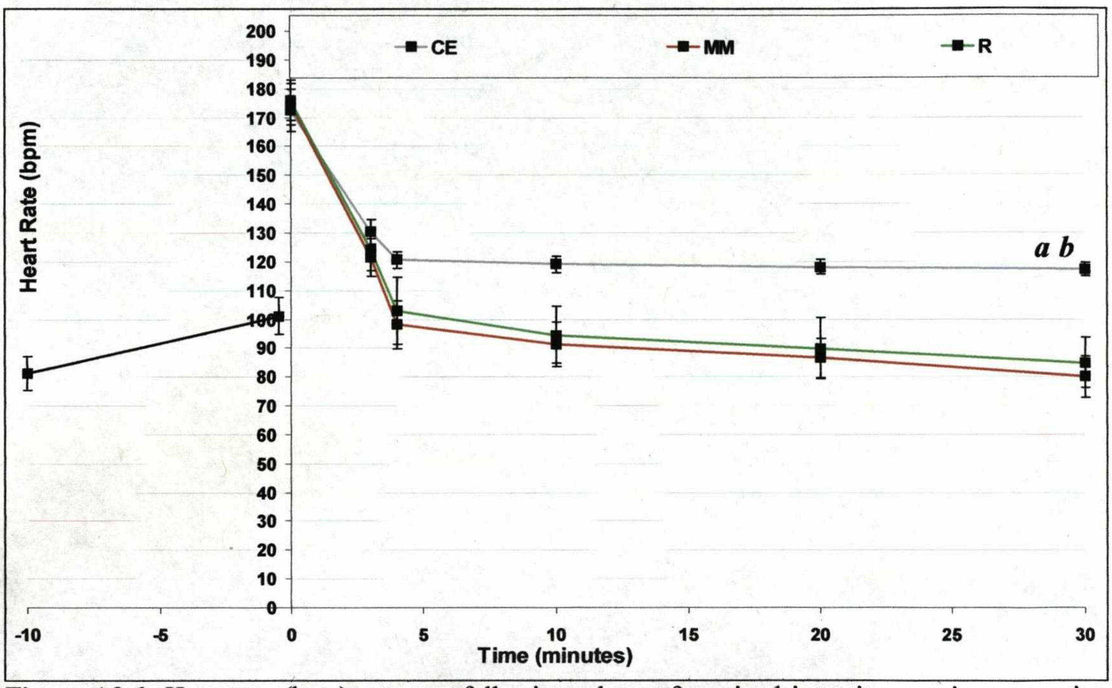


Figure A2.6 Heart rate (bpm) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM and ***b*** = CE *vs* R (n = 10).

8.13 The effect of a manual leg massage on systolic and diastolic blood pressure

8.13.1 Systolic blood pressure: Baseline SBP was 118.2±5.7mmHg. For all conditions, the highest SBP (168.6±0.6mmHg) was measured on completion of the WAnT, followed by a decrease over time. This corresponded with a similar trend in the heart rate. No differences were observed in SBP between the three conditions during recovery (Figure A2.7).

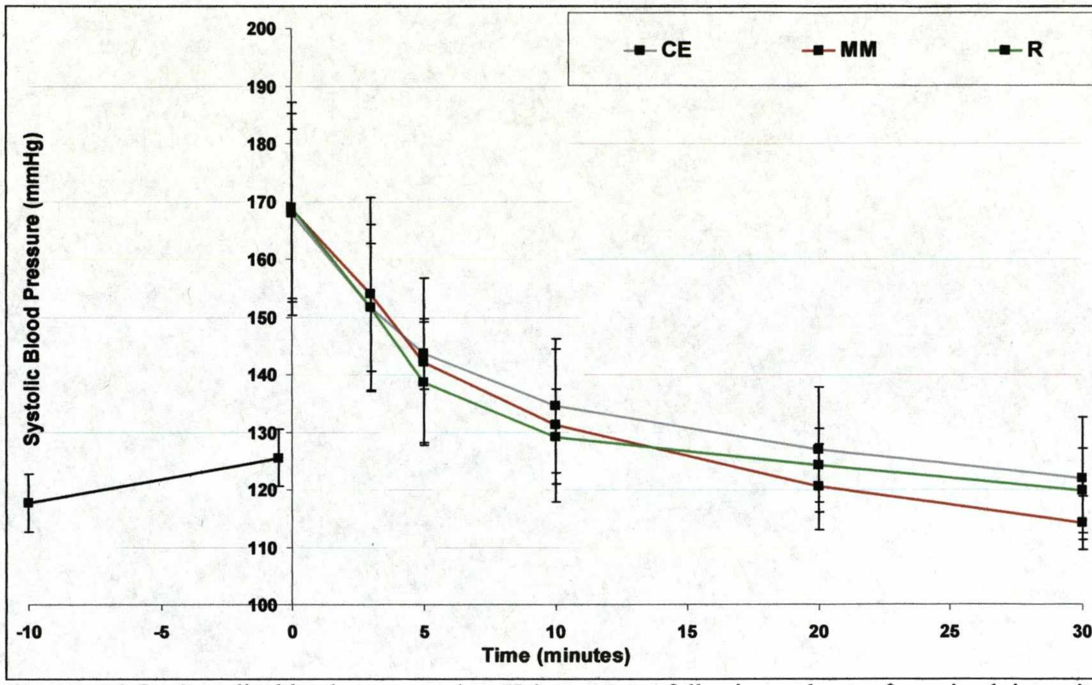


Figure A2.7 Systolic blood pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R) (n = 10).

8.13.2 Diastolic blood pressure: Baseline DBP was 74.3±2.8mmHg. A significant decrease in diastolic pressure (DBP) was seen 3mins following the completion of the WAnT for both MM and R (Figure A2.8). At 30mins post, the DBP for R and MM were 61.8±4.8mmHg and 63.8±5.2mmHg, which contrasted to the baseline of 74.0±3.4mmHg and 74.6±3.4mmHg respectively; indicating that, for R and MM, the DBP had not returned to baseline by 30mins.

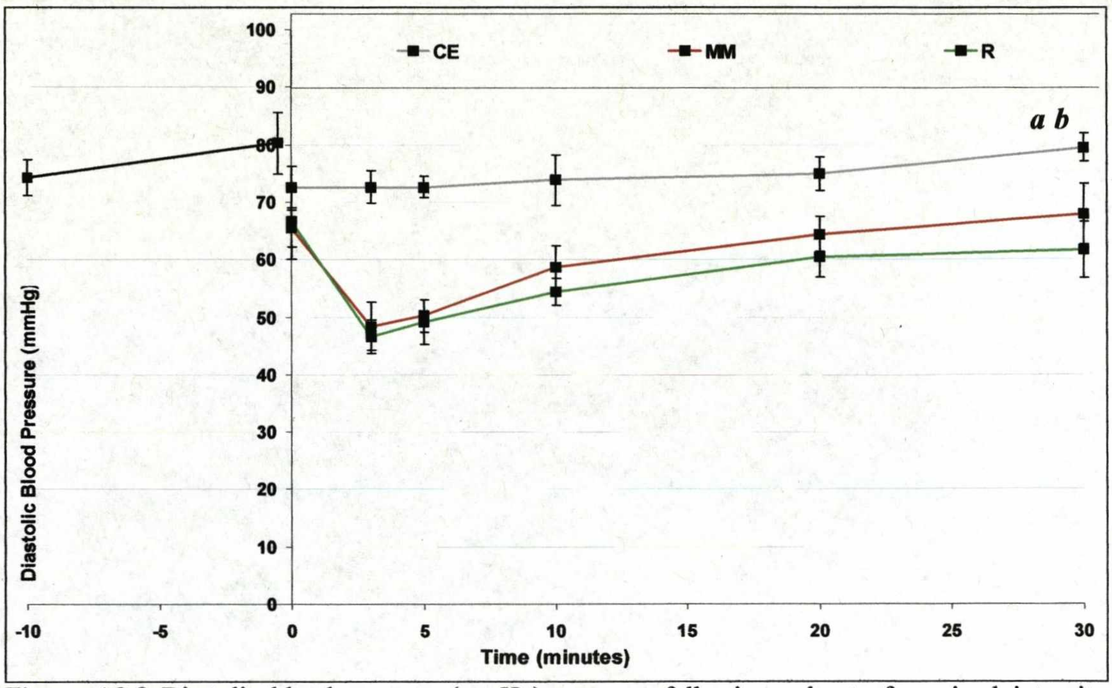


Figure A2.8 Diastolic blood pressure (mmHg) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences for diastolic blood pressure ***a*** = CE *vs* MM and ***b*** = CE *vs* R (n = 10).

In conclusion, the results indicate that manual leg massage did not prevent diastolic undershoot, similar to the trend seen during R. Although the DBP for CE decreased slightly following the WAnT, DBP was maintained.

8.14 The effect of manual leg massage on rate pressure product

Baseline RPP was 9364±947units; which increased to 29967±2672units on completion of the WAnT (Figure A2.9), and was followed by a gradual decrease over time for all three recovery methods due to the decrease in heart rate and systolic blood pressure. The RPP for MM (9134±867units) was significantly lower (p=0.012) than that of R (10200±952units), and both were significantly lower than the recumbent cycling method of recovery. Predictably, the RPP for CE remained elevated at 14292±1221units at the end of the 30mins recovery.

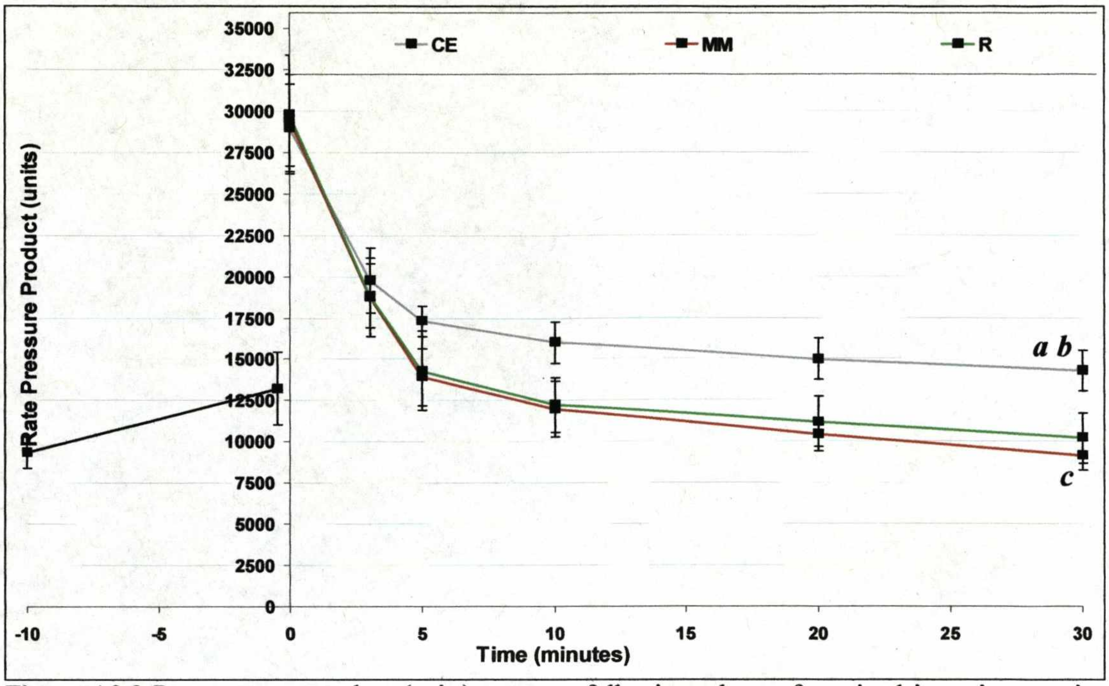


Figure A2.9 Rate pressure product (units) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM, ***b*** = CE vs R and ***c*** = MM *vs* R (*n* = 10).

8.15 Interaction between rate pressure product, heart rate and blood pressure

Rate pressure product has been shown to be related more to HR than SBP (Herminda *et al.*, 2001). This was confirmed during the present study, where RPP correlated highly with HR (r^2 = 0.9279), and not so highly with SBP (r^2 = 0.5886) (Figure A2.10). The data presented is pooled data from the three conditions for all time points.

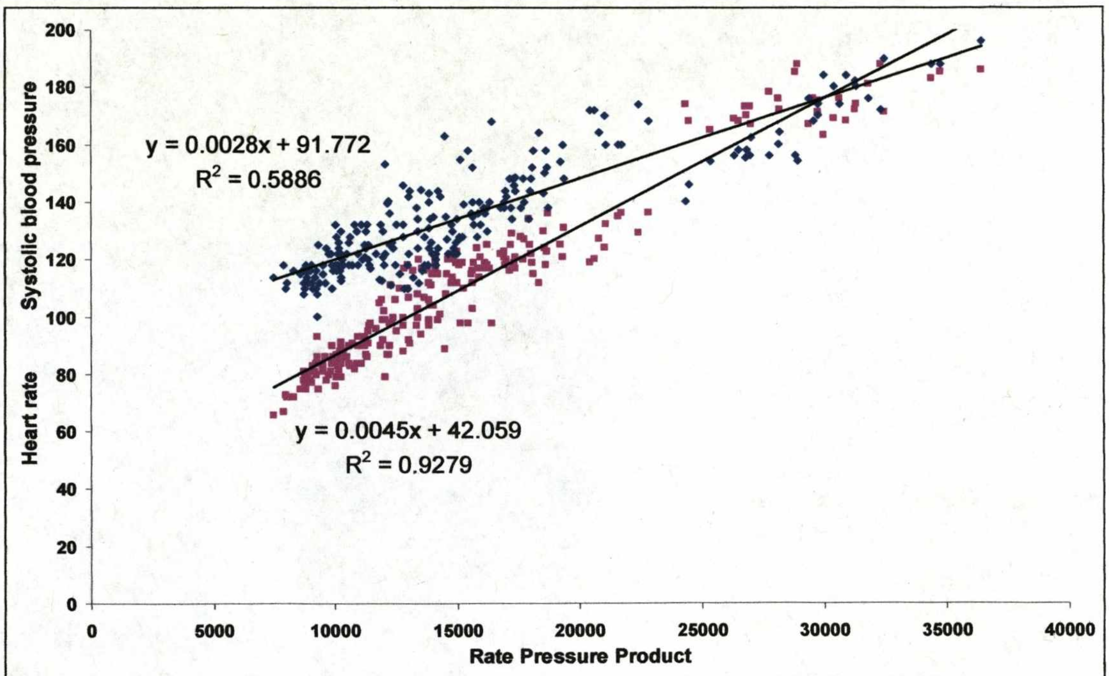


Figure A2.10 Correlation (r^2) between Rate Pressure Product and Systolic Blood Pressure or Heart Rate.

8.16 The effect of a manual leg massage on pulmonary ventilation

8.16.1 Respiratory rate: Baseline respiratory rate was 17.1±1.1cycles · min^{-1} (Table A2.5). On completion of the WAnT this increased to 56.1±17.2cycles · min^{-1}, and was followed by a gradual decrease over time for all three recovery methods. At the end of the 30min recovery period, RR for MM (17.4±2.0cycles · min^{-1}) was significantly lower (p=0.017) than that of R (19.3±2.1cycles · min^{-1}). Both were significantly lower (p<0.0001) than the recumbent cycling method of recovery (29.8±4.4cycles · min^{-1}) which predictably remained elevated.

8.16.2 Tidal volume: Baseline tidal volume was 0.6±0.03litres (Table A2.5). On completion of the WAnT this increased to 2.3±0.6litres, and was followed by a gradual decrease over time for all three recovery methods. At the end of the 30min recovery period V_T for MM (0.6±0.1litres) was significantly higher (p<0.01) than that of R (0.5±0.05 litres). Both were significantly lower (p<0.0001) than the recumbent cycling method of recovery (1.0±0.3litres) which predictably remained elevated.

8.16.3 Pulmonary ventilation: Baseline pulmonary ventilation was 9.8±1.1l · min^{-1} (Table A2.5). On completion of the WAnT this increased to 129.1±19.3 l · min^{-1}, and was followed by a decrease over time for all three recovery methods. At the end of the 30min recovery period there was no significant difference in the VE for MM (10.3 ± 2.3 l · min^{-1}) compared to that of R (10.0 ± 1.9 l · min^{-1}). Due to the active exercise recovery, VE for CE was significantly higher than the other two recovery conditions.

Table A2.5 Respiratory variables following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R) (n = 10). Significant differences ***a*** = CE *vs* MM, ***b*** = CE *vs* R and ***c*** = MM *vs* R (n = 10).

	Baseline	On completion of WAnT	3mins post WAnT	5mins post WAnT	10mins post WAnT	20mins post WAnT	30mins post WAnT
Respiratory rate (RR) (cycles · min^{-1})							
CE	17.1±1.1	56.1±17.2	36.4±4.4***ab***	32.3±4.1***ab***	31.6±4.0***ab***	30.4±3.9***ab***	29.8±4.4***ab***
MM			36.9±4.0	30.3±3.8	26.4±2.6	21.8±2.1	17.4±2.0***c***
R			35.2±2.1	29.2±2.7	25.2±2.9	22.0±3.1	19.3±2.1
Tidal volume (V_T) (litres)							
CE	0.6±0.03	2.3±0.6	1.5±0.4	1.4±0.2***ab***	1.2±0.2***ab***	1.1±0.2***ab***	1.0±0.3***ab***
MM			1.3±0.3	1.1±0.2	0.8±0.1	0.6±0.1	0.6±0.1***c***
R			1.3±0.2	1.2±0.1	0.9±0.1	0.7±0.1	0.5±0.1
Pulmonary ventilation (VE) (litres · min^{-1})							
CE	9.8±1.1	129.1±19.3	54.6±8.8***ab***	45.3±7.7***ab***	36.3±3.9***ab***	33.0±3.6***ab***	30.6±3.5***ab***
MM			49.1±8.3	33.5±5.5	22.1±3.5	13.6±3.2	10.3±2.3
R			47.3±7.9	34.6±4.7	22.4±4.0	14.6±2.7	10.0±1.9

In conclusion, following the 30min leg massage, respiratory rate, tidal volume and pulmonary ventilation were significantly different from R.

8.17 The effect of a manual leg massage on metabolic rate

8.17.1 Oxygen uptake: Oxygen uptake (Figure A2.11) increased significantly from a baseline of 4.6 ± 0.3ml O_2 kg^{-1} min^{-1} to 42.9 ± 6.8ml O_2 kg^{-1} min^{-1} following the WAnT. The values for R and MM continued to decrease gradually towards baseline throughout the recovery period; with CE remaining relatively constant due to the stable work rate. A comparison of the respective VO_2 values at 30mins post showed a significant difference between CE and the other two conditions ($p<0.001$). There was no significant difference between R (4.8 ± 0.8ml O_2 kg^{-1} min^{-1}) and MM (5.9 ± 0.8ml O_2 kg^{-1} min^{-1}).

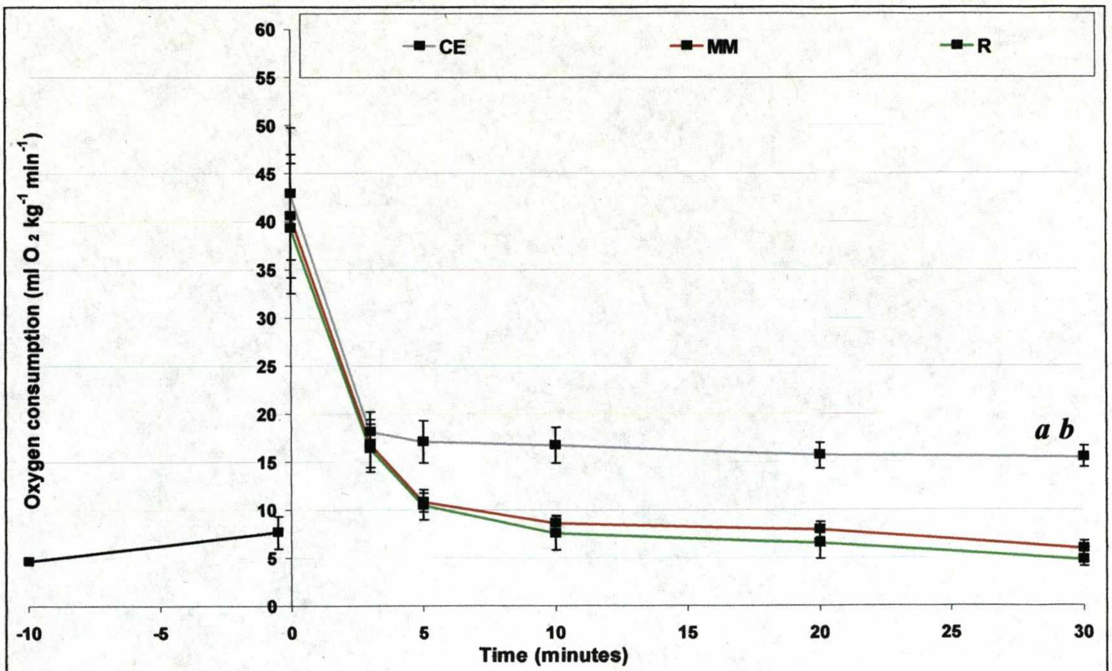


Figure A2.11 Oxygen uptake (ml O_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM and ***b*** = CE *vs* R (*n* = 10).

8.17.2 Carbon dioxide output: Carbon dioxide output increased from 3.6±0.3 to 49.8±8.3ml CO_2 kg^{-1} min^{-1} immediately post WAnT. Analysis showed there was no significant difference between VCO_2 output for MM and R at the end of recovery period. Both were significantly lower than CE (p<0.001). By 30mins post VCO_2 for R was 4.1±0.7ml CO_2 kg^{-1} min^{-1}, compared to 4.9±0.8ml CO_2 kg^{-1} min^{-1} for MM (Figure A2.12).

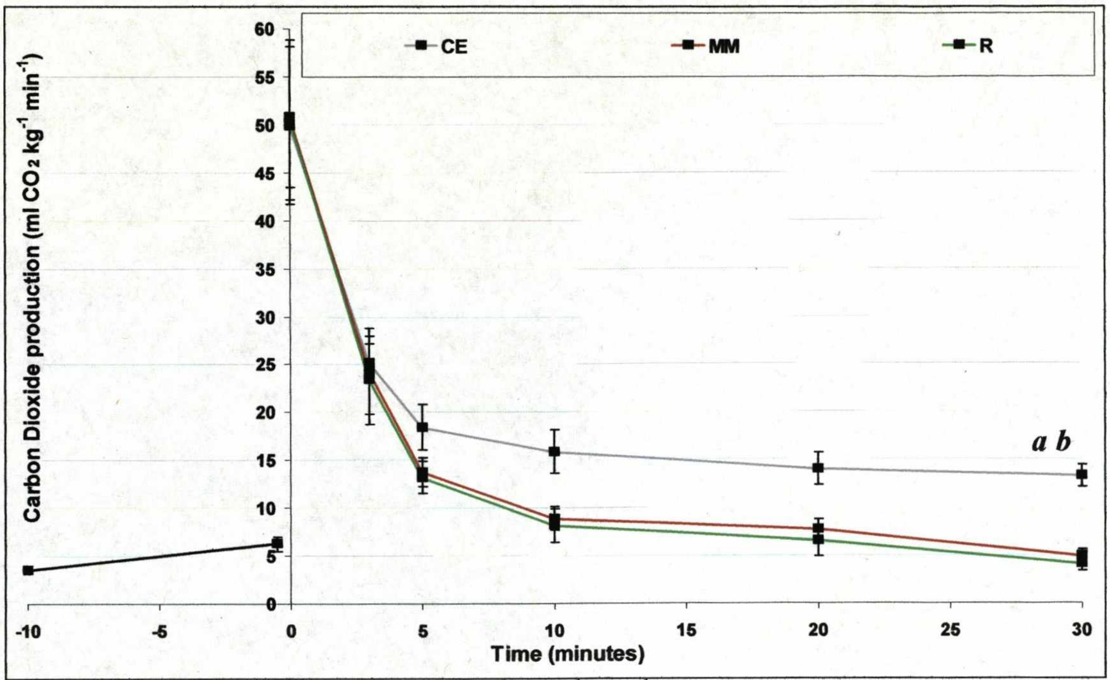


Figure A2.12 Carbon dioxide output (ml CO_2 kg^{-1} min^{-1}) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and Rest (R). Significant differences (p<0.05) ***a*** = CE *vs* MM and ***b*** = CE *vs* R (n = 10).

8.17.3 Respiratory Exchange Ratio: Baseline respiratory exchange ratio was 0.75±0.02. This increased to 1.38±0.11 (CE), 1.43±0.12 (MM) and 1.41±0.12 (R) at 3mins post WAnT, reflecting considerable metabolic acidosis during the early part of the recovery phase for all conditions (Figure A2.13). RER decreased, but at 30mins post had not returned to baseline (0.85±0.02 (CE), 0.90±0.03 (MM) and 0.88±0.05 (R). Analysis showed that RER was highly correlated with BLa (r^2 = 0.813 (CE), 0.988 (MM) and 0.992 (R)). In conclusion, MM had no greater effect on metabolic rate compared to R.

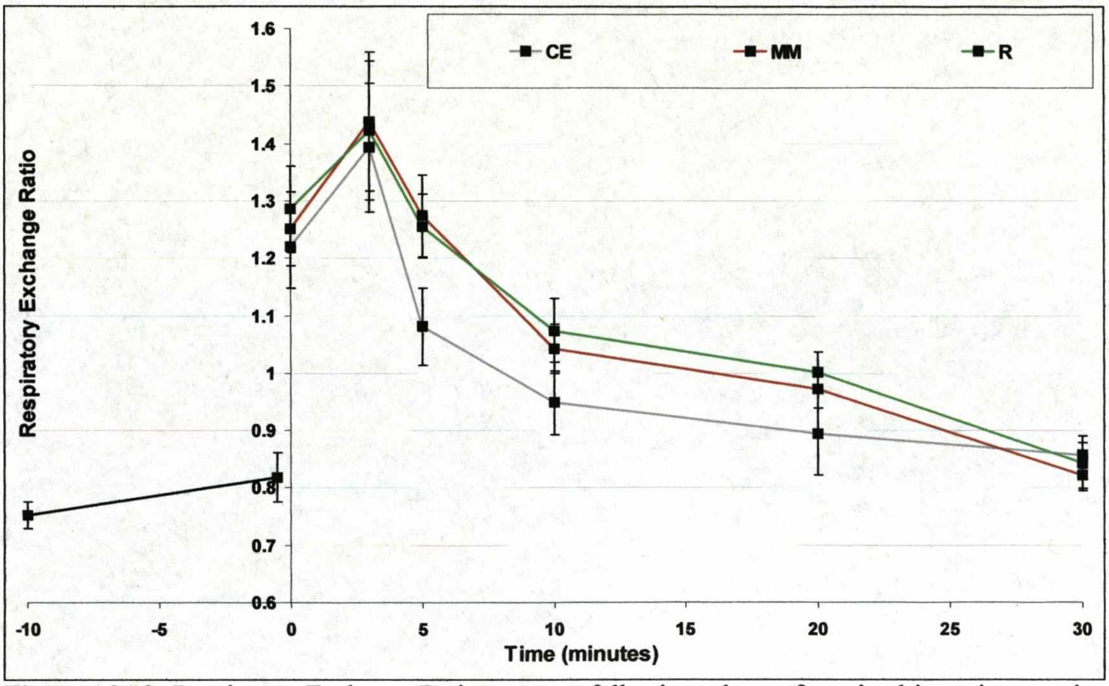


Figure A2.13 Respiratory Exchange Ratio response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R) (n = 10). Significant differences ***a*** = CE *vs* MM and ***b*** = CE *vs* R (n = 10).

8.18 The effect of massage on body temperature

8.18.1 Leg skin temperature Leg_{Temp}: Baseline Leg_{Temp} was 31.4±0.8°C and at 15mins post the Leg_{Temp} for R was 31.5±0.5°C, with the value for MM (34.0±0.7°C) being significantly higher (p<0.01). The Leg_{Temp} for CE at the same time point was 32.1±0.7°C (Table A2.6).

Table A2.6 Leg temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences a = CE *vs* MM and c = MM *vs* R (n = 10).

	Baseline	During (15-20mins)	Immediately post recovery (30 - 35mins)
CE	31.4±0.8	32.2±0.6	32.1±0.5
MM	31.4±0.8	34.0±0.6 ***a c***	33.7±0.7 ***a c***
R	31.4±0.5	31.5±0.4	31.4±0.4

8.18.2 Aural temperature ($Aural_{Temp}$): Baseline measurement of $Aural_{Temp}$ was 36.8±0.2°C (Figure A2.14). A small increase was observed in $Aural_{Temp}$ for all conditions following the completion of the WAnT. During recovery, there was no significant difference seen between R and MM. The 30mins post $Aural_{Temp}$ was

37.7±0.23°C for CE, but significantly lower (p<0.01) for the other two conditions (R 37.0±0.12°C and MM 37.3±0.19°C).

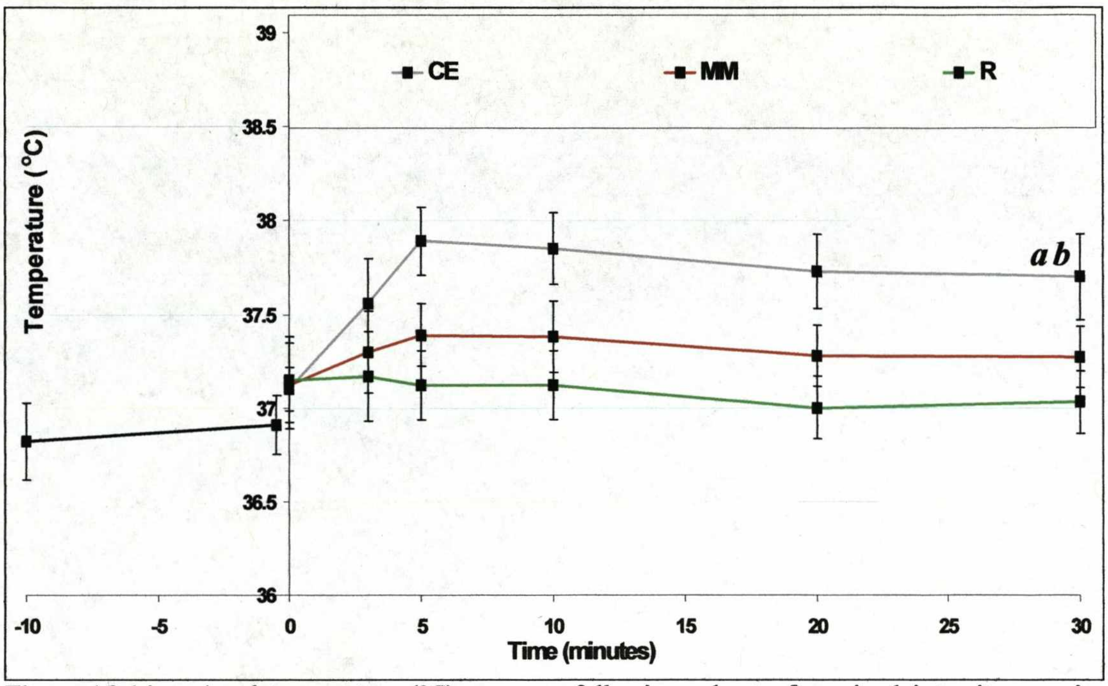


Figure A2.14 Aural temperature (°C) response following a bout of maximal intensity exercise comparing manual leg massage (MM) with recumbent cycling exercise (CE) and rest (R). Significant differences ***a*** = CE *vs* MM and ***b*** = CE *vs* R (*n* = 10).

5.19 The effect of manual leg massage on perception of feeling

PoF decreased from +6 (IQR 5, 6) (Very Good) to -2 (IQR -0.25, -2.75) (Fairly Bad) for all conditions following the WAnT. Feeling further deceased during R to 4 (IQR 3, 4.75) at 3mins post. PoF subsequently improved over the 30min recovery period at different rates (Figure A2.15). Significant differences were seen between the MM vs R (p=0.005) and MM *vs* CE (p=0.007) at the end of the recovery period; the 30min values indicated that MM had the greater effect, with subjects reporting feeling "Very Good" (6 IQR 5.25, 6). In contrast, during CE, subjects only reported feeling "Good" (4 IQR 3.25, 5), or "Fairly Good" (2 IQR 2, 3) during R.

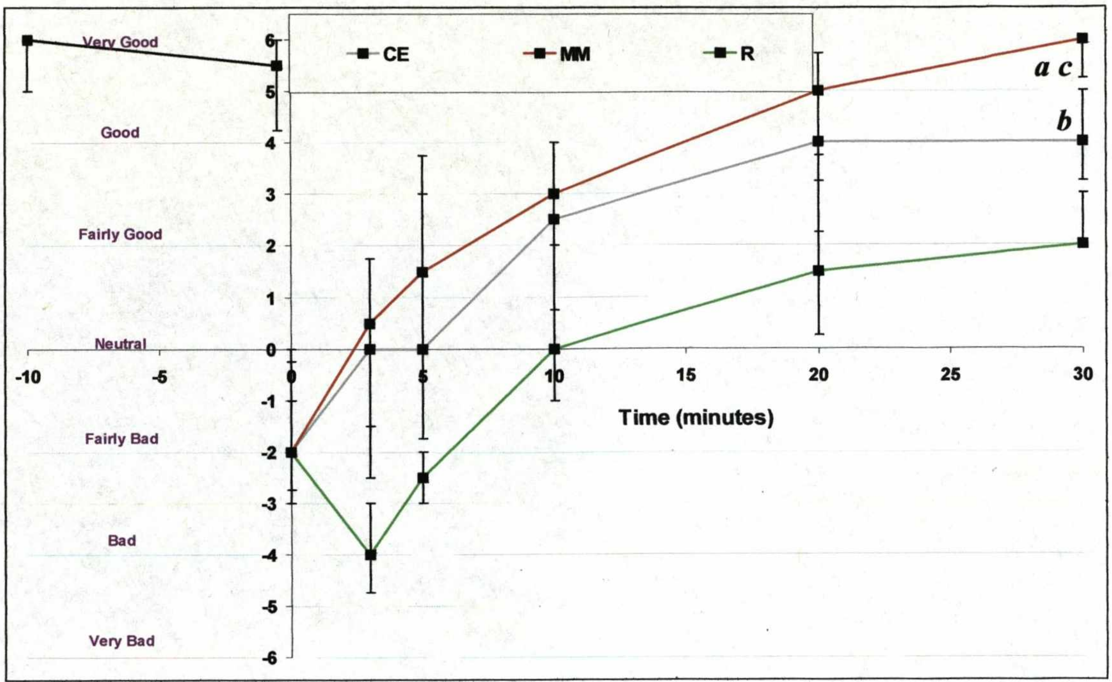


Figure A2.15 Perception of Feeling response following a bout of maximal intensity exercise for 30mins recumbent Cycling Exercise (CE), Manual leg Massage (MM) and Rest (R). Significant differences ***a*** = MM *vs* CE, ***b*** = CE *vs* R and ***c*** = MM *vs* R (***n*** = 10).

8.20 Interaction between perception of feeling, blood lactate concentration and diastolic pressure following a 30sec WAnT

Analysis showed significant correlations exist between BLa and PoF, and also between PoF and DBP. Analysis (Table A2.7) was performed on the data from 3mins post (corresponding with the highest in lactate, lowest diastolic pressure and lowest perception of feeling) to 30mins post WAnT (end of the recovery period). The results indicate that as BLa decreases PoF improves. Furthermore, the results indicate that as DBP decreases, there is an improvement in PoF. During recovery, both variables increase towards baseline.

Table A2.7 Correlation analysis (r^2) between Blood lactate and Perception of Feeling; and Perception of Feeling and Diastolic blood pressure for 30mins recumbent Cycling Exercise (CE), Manual leg Massage (MM) and Rest (R).

	Perception of Feeling & Blood Lactate	**Perception of Feeling & Diastolic Blood Pressure**
MM (30mins manual leg massage)	0.984	0.987
R (30mins Rest)	0.987	0.995
CE (30mins recumbent Cycling Exercise)	0.992	0.815

In conclusion, the results clearly show a positive perceptual effect exerted during manual leg massage. Despite manual leg massage not preventing diastolic undershoot, and not clearing lactate as effectively as CE, it did have a greater impact on the subject's perception of how they felt.

8.21 Conclusions

8.21.1 Manual leg massage decreased BLa concentrtaion compared to Rest, post exercise

8.21.2 Continued low intensity cycling exercise decreased blood lactate concentration more rapidly than the other conditions.

8.21.3 Manual leg massage had no effect on systolic blood pressure, but did have an effect on rate pressure product which reduced due to a decrease in heart rate compared to Rest, post exercise.

8.21.4 Manual leg massage did not prevent a decrease in diastolic blood pressure compared to Rest, post exercise.

8.21.5 Manual leg massage had an effect on breathing frequency, which decreased during treatment indicating a parasympathetically mediated response.

8.21.6 Manual leg massage had no effect on metabolic rate compared to Rest, post exercise.

8.21.7 Manual leg massage enhanced perception of feeling following a short bout of maximum intensity cycling exercise, compared to Rest.

8.21.8 The decrease in perception of feeling followed the drop in diastolic pressure with Rest, but did not with MM. Thus, diastolic blood pressure does not seem to be related to perception of feeling in all conditions.

APPENDIX 3

The effect of controlled and spontaneous breathing on components of heart rate variability

INTRODUCTION

9.1 Overview

Continuous changes in the sympathetic and parasympathetic balance induces the sinus rhythm to fluctuate around the mean HR. The heart rate shows fluctuations which are equal in frequency to the breathing frequency because of inspiratory inhibition of the vagal tone (vanRavenswaaij-Arts *et al.*, 1993). This inhibition of the vagal tone is evoked largely by impulses sent from the medulla respiratory centre to the cardiac centre. The HF component of HRV has a frequency range that corresponds to respiration rate and thus reflects respiratory sinus arrhythmia (RSA). The parasympathetic branch of the autonomic nervous system is ultimately responsible for transmitting the RSA (Akselrod *et al.*, 1981; Task force, 1996; Brenner, Thomas & Shepard, 1997; Delaney and Brodie, 2000; Stark, Schienle, Walter & Vaitl, 2000).

Porges and Byrne (1992) suggest that the cortical effort of matching an externally-paced rhythm for breathing frequency induces changes in the autonomic control of the heart. In addition, research is conflicting regarding the influence that paced breathing has on HRV. Patwardhan *et al.*, (1995) showed no significant changes in HF, and therefore vagal control, when paced breathing was compared to un-paced breathing. This was also true for Stark, Schienle, Walter & Vaitl (2000) who reported a significant decrease in HRV, but did not observe a significant decrease in the HF component of HRV.

There is much contention regarding controlled or spontaneous breathing frequency during the measurement of HRV. Stark, Schienle, Walter & Vaitl (2000) suggest that breathing frequency (BF) should be controlled when interpreting HRV data due to increases in BF. In turn, this will result in a decrease in the HF component, and a failure to control breathing will cause difficulty in the interpretation of results between treatment conditions. This is because it will prove difficult to distinguish between treatment effect and the result of a change in BF (Stark, Schienle, Walter & Vaitl 2000). Other researchers have also controlled BF and purport that any changes in HRV are from the treatment and not alterations in BF (Hirsch & Bishop, 1989).

9.2 Study aims

The aim of the present study was to observe whether there was a cortical effect of controlling breathing to 0.2Hz, when compared to a matched spontaneous breathing frequency. Therefore, if there was a significant reduction in the HF component, this would highlight the need to control breathing when administering massage in the present investigations. However, if there was no significant reduction in the high frequency component this would negate the need to control breathing.

MATERIALS AND METHODS

9.3 Subjects

18 male subjects (mean±SD age 21±1.3yrs; weight 78.7±7.2kg and height 181.6±4.9cm) participated within the study. Each subject arrived at the laboratory in a 1 hour post-prandial condition, having not exercised, consumed caffeine, or alcohol for at least 24 hours prior to all testing. Room temperature was controlled between 21 - 24°C.

9.4 Breathing conditions

9.4.1 *Spontaneous breathing:* Subjects were seated in a comfortable position, and were requested to remain in that position for the duration of the trial. The subjects were then required to have 15mins of seated rest, during which time they were instructed not to talk or move. This was followed by a further 5mins during which time the heart rate was monitored.

9.4.2 *Controlled breathing:* Subjects were required to breathe at a set rate for 20mins, and used a stopwatch to monitor their breathing. The rhythm was maintained at one cycle every five seconds (12 cycles $\cdot$ min^{-1}). Breathing rate was closely monitored by the researchers at all times in order to prevent hyperventilation. After 15mins, heart rate was monitored for a further 5mins.

RESULTS

9.5 Heart Rate Variability

Table A3.1 shows the mean results representing the sympathetic and parasympathetic indicators of HR control. Breathing was maintained at 0.20 (±0.0)Hz (12.0 (±0.0) cycles · $mins^{-1}$) during the controlled breathing (CB) trials, or at 0.20±0.9Hz (12.5±1.9cycles · $mins^{-1}$) during the spontaneous breathing (SB) trials. There were no significant differences between the CB and SB trials.

Table A3.1 - The effect of controlled breathing (CB) (0.20±0.0Hz) and spontaneous breathing (SB) (0.20±0.9Hz) on heart rate, LF norm, LF:HF Ratio, HF norm, RMSSD and pNN50. Data presented as the mean±SD (*n* = 18). **Parasympathetic**, **Sympathetic** and **Sympathovagal** indicators.

	Controlled breathing	Spontaneous breathing
Heart rate (bpm)	74.3±17.2	73.9±15.3
LF norm (%)	65.3±22.4	64.5±22.3
LF:HF Ratio	4.6±5.6	4.2±5.6
HF norm (%)	34.6±22.4	35.5±22.3
RMSSD (ms)	47.1±27.9	49.0±27.6
pNN50 (%)	12.7±9.8	14.1±9.5

Figures A3.1 and A3.2 are power spectral density graphs (PSD) that show the frequency domain data, analysed using fast fourier transform (FFT) analysis. These graphs compare one subject when breathing frequency (BF) was controlled. Controlled breathing causes an increase in the size of the spike at 0.2 Hz, which is equivalent to 12cycles · min^{-1}. The other components of HRV (VLF and LF) were not affected through controlling breathing when compared to spontaneous breathing.

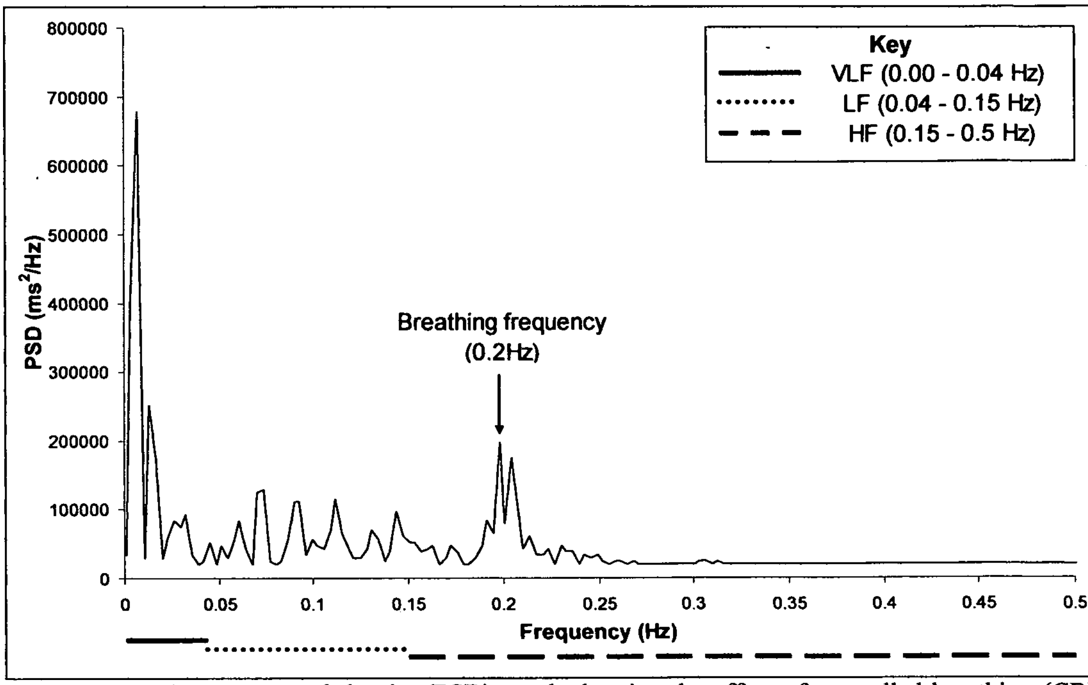


Figure A3.1 - Power spectral density (PSD) graph showing the effect of controlled breathing (CB). Graph depicts the power distribution of the HRV components. The areas on the graph that are represented by the VLF, LF and HF frequencies are depicted by the different lines (refer to the key). Results were obtained during seated rest when breathing frequency was controlled (CB) at 0.20±0.0Hz (n = 1) at room temperature (21 - 24°C) for a period of 5mins.

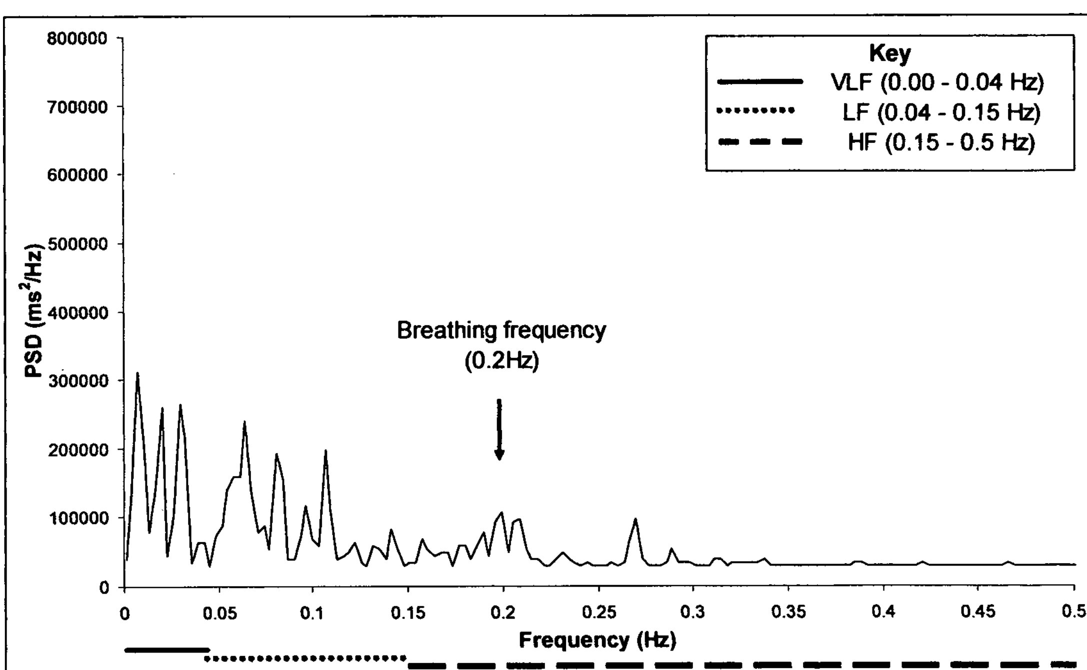


Figure A3.2 - Power spectral density (PSD) graph showing the effect of spontaneous breathing (SB). Graph depicts the power distribution of the HRV components. The areas on the graph that are represented by the VLF, LF and HF frequencies are depicted by the different lines (refer to the key). Results were obtained during seated rest when breathing frequency was spontaneous (SB) at 0.20±0.9Hz (n = 1) at room temperature (21 - 24°C) for a period of 5mins.

Figure A3.3 and A3.4 show typical R-R interval tachograms for a single subject during the CB and SB trials. The similarities in the mean interval time between the tachograms suggest there were no differences between controlled and spontaneous breathing on the R-R intervals.

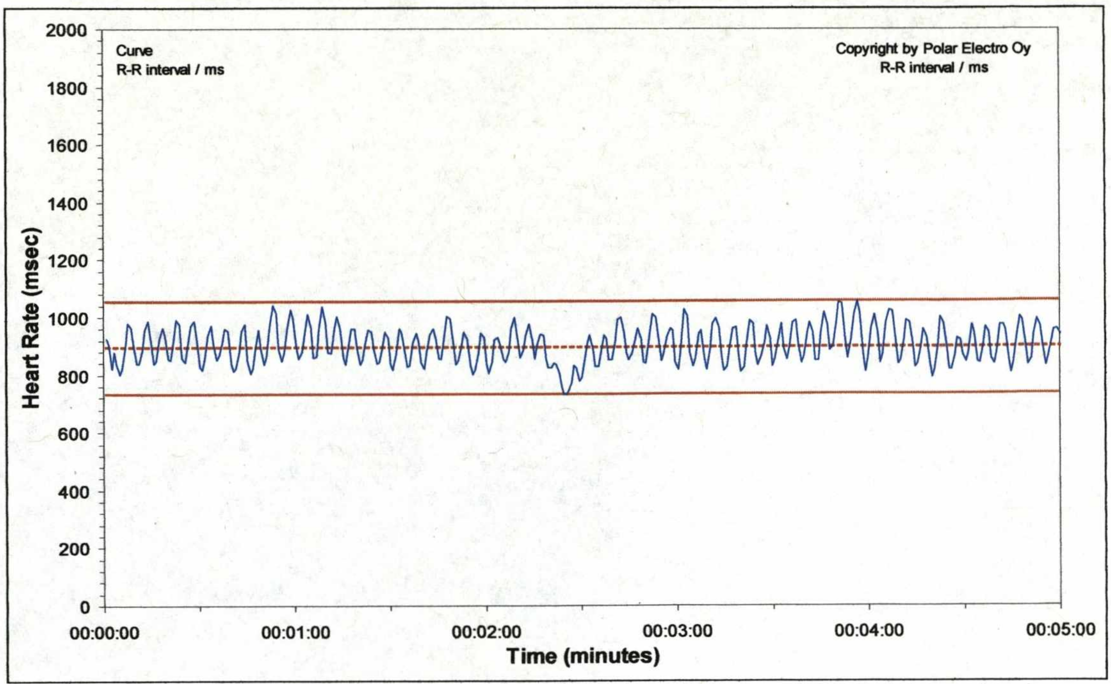


Figure A3.3 – The effect of controlled breathing (CB) using a heart rate (HR) R-R interval tachogram (Polar software (Finland, Oy)). Data was obtained in at an ambient room temperature which was maintained between 21 - 24°C, with the subject seated rest for a period of 5mins. Breathing frequency was controlled at 0.20±0.0Hz.

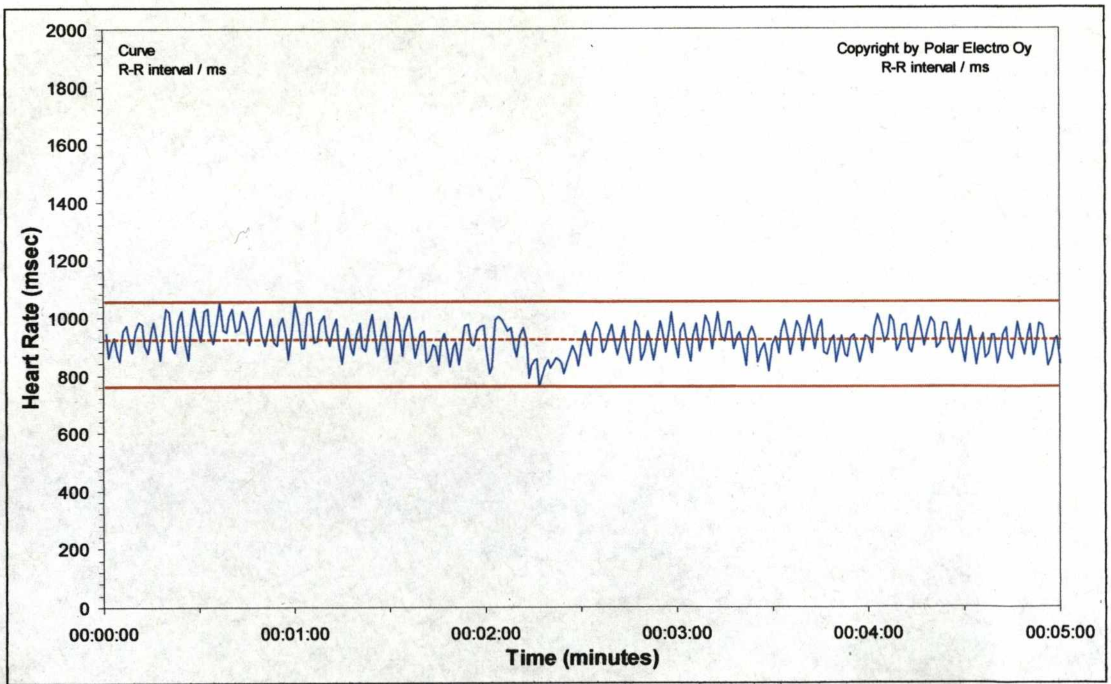


Figure A3.4 – The effect of spontaneous breathing (SB) using a heart rate (HR) R-R interval tachogram (Polar software (Finland, Oy)). Data was obtained in at an ambient room temperature which was maintained between 21 - 24°C, with the subject seated at rest for a period of 5mins.

9.6 Conclusions

The results of the present investigation confirm that there were no differences between the R-R interval tachograms or the components of frequency domain components of HRV when breathing was controlled or spontaneous. Therefore, during data collection of HRV in the present investigations, breathing frequency would not be controlled.

Appendix 4.1

DEPARTMENT OF BIOLOGICAL SCIENCES

Pre-test Health Questionnaire

(PLEASE NOTE THAT THIS INFORMATION WILL BE CONFIDENTIAL)

Name:................................. **DOB:................** **Age:...........**

Project Title:...

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you are fit and healthy enough to participate in this research project.

	Yes	No
1. Have you in the past suffered from a serious illness or accident.	☐	☐

If Yes, please provide details

....
....
....
....

	Yes	No
2. Have you consulted your doctor the last 6 months	☐	☐

If Yes, please provide details

....
....
....
....

3. Do you suffer, or have you suffered from:

	Yes	**No**
Asthma	☐	☐
Diabetes	☐	☐
Bronchitis	☐	☐
Epilepsy	☐	☐
High blood pressure	☐	☐

	Yes	No
4. Is there any history of heart disease in your family	☐	☐

	Yes	No
5. Are you suffering from any infectious skin diseases, sores, wounds, or blood infections i.e., Hepatitis B, HIV, etc.?	☐	☐

If Yes, please provide brief details

....
....

	Yes	No
6. Are you currently taking any medication If Yes, please provide details	☐	☐

....
....
....

	Yes	No
7. Are you suffering from a disease that inhibits the sweating process	☐	☐

	Yes	No
8. Is there anything to your knowledge that may prevent you from participating in the testing that has been outlined to you? If Yes, please provide details	☐	☐

....
....
....
....

Your Recent Condition

	Yes	No
• Have you eaten in the last 2 hours? If Yes, please provide details	☐	☐

....
....

	Yes	No
• Have you consumed alcohol in the last 24hr	☐	☐
• Evaluate your diet over the last two days: Poor Average Good Excellent		
• Have you had any kind of illness or infection in the last 2 weeks	☐	☐
• Have you exercised in the last 2 days? If Yes, please describe below	☐	☐

....
....
....
....

You will not be permitted to take part in the experiment if you:

- have a known history of medical disorders (i.e. hypertension, heart or lung disease)
- have a fever, suffer from fainting or dizzy spells
- are currently unable to train because of a joint or muscle injury
- have had any thermoregulatory disorder
- have gastrointestinal disorder
- have a history of infectious diseases (i.e. HIV or Hepatitis B)
- have, if pertinent to the study, a known history of rectal bleeding, anal fissures, haemorrhoids or any other similar rectal disorder.

Declaration

My responses to the above questions are true to the best of my knowledge and I am assured that they will be held in the strictest confidence.

Name: (Participant).. Date:......................

Signed (Participant): ....

Name: (Investigator) **Gareth Elfed Jones**...................... Date:............

Signed (Investigator): Gareth Elfed Jones

Appendix 4.2

The effect of whole leg massage administered at rest

1. Mr Gareth Elfed Jones and Prof. David Cotterrell have requested my participation in a research study at this institution.

2. "I have been informed that the purpose of the research project is to investigate the effect of a 30mins leg massage administered at rest."

"My participation will involve...
- having my weight and height recorded.
- either resting on a treatment couch in a supine/prone position for 30mins, or receiving a 30mins manual leg massage, or receiving a 30mins vibratory leg massage.
- having my heart rate and blood pressure taken several times.
- wearing a mask in order to record my respiration.
- having my temperature taken in my ear and on the skin of my leg.

All the tests detailed will be completed within 1 hour.

3. "I have been informed that my participation will involve minimal risk.

4. "I understand that in case of injury, on campus first aid and/or off campus treatment will be given. If I have any questions about my rights as a subject in this research, or I feel I have been placed at risk, I can contact the Head of Department."

5. "I understand that the results of the research may be published, however my name or identity will not be revealed. In order to maintain confidentiality, until publication, only the investigator named above will have access to the information collected."

6. "I have been informed that I will not be compensated for my participation."

7. "I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by the investigator or Prof. David Cotterrell.

8. "I have read all the above information, the information sheet; and the nature, demands and benefits of the project have been explained to me. I knowingly acknowledge the risks involved, and understand that I may withdraw my consent and discontinue participation at anytime. A copy of this consent form will be given to me."

Subject's signature____________________ **Date**________

9. "I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study; have answered any questions that have been raised, and have witnessed the above signature."

10. "I have provided the subject with a copy of this consent document."

Investigator's signature Gareth Elfed Jones **Date**________

Appendix 4.3

The effect of single leg calf massage administered at rest

1. Mr Gareth Elfed Jones and Prof. David Cotterrell have requested my participation in a research study at this institution.

2. "I have been informed that the purpose of the research project is to investigate the effect of massage on limb haemodynamics and cardiac autonomic function"

"My participation will involve...
- having my weight and height measured.
- resting on a treatment couch in a prone position for a maximum of 10mins, and receiving a manual or vibratory calf massage.
- having 4 small electrode thermometers placed on both calf's; and one electrode placed in my ear.
- having blood volume in my legs indirectly measured using an air plethysmograph.
- having my calf circumference measured.
- having my blood pressure and heart rate taken.

All the tests detailed will be completed within 1 hour.

3. "I have been informed that my participation will involve minimal risk.

4. "I understand that in case of injury, on campus first aid and/or off campus treatment will be given. If I have any questions about my rights as a subject in this research, or I feel I have been placed at risk, I can contact the Head of Department."

5. "I understand that the results of the research may be published, however my name or identity will not be revealed. In order to maintain confidentiality, until publication, only the investigator named above will have access to the information collected."

6. "I have been informed that I will not be compensated for my participation."

7. "I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by the investigator or Prof. David Cotterrell.

8. "I have read all the above information, the information sheet; and the nature, demands and benefits of the project have been explained to me. I knowingly acknowledge the risks involved, and understand that I may withdraw my consent and discontinue participation at anytime. A copy of this consent form will be given to me."

Subject's signature____________________________ **Date**__________

9. "I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study; have answered any questions that have been raised, and have witnessed the above signature."

10. "I have provided the subject with a copy of this consent document."

Investigator's signature Gareth Elfed Jones **Date**__________

Appendix 4.4

The effect of single whole leg massage following a bout of aerobic cycling exercise

1. Mr Gareth Elfed Jones and Prof. David Cotterrell have requested my participation in a research study at this institution.

2. "I have been informed that the purpose of the research project is to investigate the effect of massage on limb haemodynamics and cardiac autonomic function following a bout of aerobic exercise"

"My participation will involve...

- having my weight and height measured.
- completing a maximal oxygen uptake test on a cycle ergometer.
- exercising on cycle ergometer for 20mins at 80% of my maximum heart rate.
- resting on a treatment couch for a maximum of 30mins, and receiving a manual or vibratory leg massage on my non-dominant leg.
- having 4 small electrode thermometers placed on both calf's; and one electrode placed in my ear.
- having blood volume in my legs indirectly measured using an air plethysmograph.
- having my calf circumference measured.
- having my blood pressure and heart rate taken.
- having 8 finger prick blood samples taken, in order to measure lactate concentration.

All the tests detailed will be completed within 1 hour.

2. "I have been informed that my participation will involve minimal risk.

3. "I understand that in case of injury, on campus first aid and/or off campus treatment will be given. If I have any questions about my rights as a subject in this research, or I feel I have been placed at risk, I can contact the Head of Department."

4. "I understand that the results of the research may be published, however my name or identity will not be revealed. In order to maintain confidentiality, until publication, only the investigator named above will have access to the information collected."

5. "I have been informed that I will not be compensated for my participation."

6. "I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by the investigator or Prof. David Cotterrell.

7. "I have read all the above information, the information sheet; and the nature, demands and benefits of the project have been explained to me. I knowingly acknowledge the risks involved, and understand that I may withdraw my consent and discontinue participation at anytime. A copy of this consent form will be given to me."

Subject's signature____________________________________ **Date**____________

9. "I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study; have answered any questions that have been raised, and have witnessed the above signature."

10. "I have provided the subject with a copy of this consent document."

Investigator's signature________________________________ **Date**____________

Appendix 4.5

The effect of continuous recovery, or combining exercise and leg massage on recovery from anaerobic exercise

1. Mr Gareth Elfed Jones and Prof. David Cotterrell have requested my participation in a research study at this institution.

2. "I have been informed that the purpose of the research project is to investigate the comparison between exercise, massage (manual and vibratory) and passive rest on post exercise recovery."

"My participation will involve...

- having my weight and height measured.
- exercising maximally on a cycle ergometer for 30^{secs} (The Wingate Anaerobic Test).
- during recovery I will either exercise lightly on a cycle ergometer for 45mins ☐, receive a 45mins manual leg massage, receive a 45mins vibratory leg massage ☐, lay passively on a treatment couch for 45mins ☐, exercise lightly on a cycle ergometer followed by a bout of passive rest for 45mins ☐, exercise lightly on a cycle ergometer followed by a bout of leg massage for 45mins ☐, or exercise lightly on a cycle ergometer followed by a bout of mechanical vibratory leg massage for 45mins ☐, following the Wingate Anaerobic Test.
- having 8 small samples of blood taken from my fingers during the test period. The first will be 10 minutes before the Wingate test, with the other 7 taken immediate following the WAnT, 3, 5, 10, 20, 30 and 45mins after the completion of the exercise test.
- having my blood pressure and heart rate taken.
- having my temperature taken in my ear and on my leg skin
- wearing a mask in order to record my respiration.

All the tests detailed will be completed within 1½ hours.

3. "I have been informed that my participation will involve more than minimal risk. The risks associated with a maximal exercise test are dizziness, nausea, difficulty with, or laboured breathing, vomiting and severe fatigue."

4. "I understand that in case of injury, on campus first aid and/or off campus treatment will be given. If I have any questions about my rights as a subject in this research, or I feel I have been placed at risk, I can contact the Head of Department."

5. "I understand that the results of the research may be published, however my name or identity will not be revealed. In order to maintain confidentiality, until publication, only the investigator named above will have access to the information collected."

6. "I have been informed that I will not be compensated for my participation."

7. "I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by the investigator or Prof. David Cotterrell.

8. "I have read all the above information, the information sheet; and the nature, demands and benefits of the project have been explained to me. I knowingly acknowledge the risks involved, and understand that I may withdraw my consent and discontinue participation at anytime. A copy of this consent form will be given to me."

Subject's signature______________________________ **Date**__________

9. "I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study; have answered any questions that have been raised, and have witnessed the above signature."

10. "I have provided the subject with a copy of this consent document."

Investigator's signature______________________________ **Date**__________

Appendix 4.7

Subject Consent Form

		Please circle as necessary
Q 1	Have you read the Informed Consent Sheet?	YES / NO
Q 2	Have you had the opportunity to ask questions and discuss this study ?	YES / NO
Q 3	Who have you spoken to? ______________________________	
Q 4	Have you received satisfactory answers to all your questions ?	YES / NO
Q 5	Have you been provided with all the information that you require ?	YES / NO
Q 6	Have you been given sufficient time to consider the implications of participation before being asked to make a decision ?	YES / NO

Do you understand that you are free to withdraw from the study:-

At any time	YES / NO
Without having to give a reason for withdrawing	YES / NO
Without effect on your future care	YES / NO

You should think carefully before agreeing to take part in this study if you have answered "No" to any of the questions.

Subject's signature______________________________ **Date**______________

Researcher's signature_ **Date**______________

Appendix 4.6

The effect of an arm massage following a bout of eccentric exercise

1. Mr Gareth Elfed Jones and Prof. David Cotterrell have requested my participation in a research study at this institution.

2. "I have been informed that the purpose of the research project is to investigate the beneficial effect of massage (manual or vibratory) following eccentric arm exercise".

"My participation will involve...

- having my weight and height measured.
- calculating my 1 repetition maximum for a biceps curl
- completing 3sets x 10reps of eccentric biceps exercise at 80% of 1 maximum repetition.
- either resting, or having a manual or a vibratory massage for 8mins.
- having my blood pressure and heart rate taken.
- registering my perception of pain using a simple scale
- having small samples of blood taken from my fingers during the test period, and each day for 5 days

3. "I have been informed that my participation will involve more than minimal risk. The risks associated with unaccustomed eccentric exercise are pain, nausea, fatigue/muscle pain for several days."

4. "I understand that in case of injury, on campus first aid and/or off campus treatment will be given. If I have any questions about my rights as a subject in this research, or I feel I have been placed at risk, I can contact the Head of Department."

5. "I understand that the results of the research may be published, however my name or identity will not be revealed. In order to maintain confidentiality, until publication, only the investigator named above will have access to the information collected."

6. "I have been informed that I will not be compensated for my participation."

7. "I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by the investigator or Prof. David Cotterrell.

8. "I have read all the above information, the information sheet; and the nature, demands and benefits of the project have been explained to me. I knowingly acknowledge the risks involved, and understand that I may withdraw my consent and discontinue participation at anytime. A copy of this consent form will be given to me."

Subject's signature____________________ **Date**________

9. "I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study; have answered any questions that have been raised, and have witnessed the above signature."

10. "I have provided the subject with a copy of this consent document."

Investigator's signature Gareth Elfed Jones **Date**________